NUCLEAR ENGINEERING VOL. 4 NO. 35 FEBRUARY, 1959

Euratom Gets Under Way

THE Euratom countries' common market came into force on January 1, this year. From that date nuclear materials have been free to circulate in the community without payment of duty and subject to no quota restriction; in addition a common external tariff has been established for two classes of goods, which can be classified as; (1) fissile and fertile materials; (2) equipment and materials directly related to nuclear technology.

For goods in the first category which include uranium, plutonium and thorium compounds, all tariffs (with one small exception) will be removed in accord with the principle established in the original treaty that they would be reduced to correspond to the lowest, currently in force on Jan. 1, in any of the member states. In the second category, which covers items ranging from heavy water compounds to shielded transport vehicles and reactors to mechanical manipulators (but excluding "free hand" handling devices), the tariff will vary between 0 and 12%. For complete reactors and reactor components the level has been set at 10% but duty will be suspended until Jan. 1, 1962, and consideration will be given to extending this period.

Euratom is to be congratulated on the boldness and the realism implicit in these measures. They are more far-reaching in some respect than those contemplated by the European Economic Community and have been instituted with a minimum of strife and, furthermore, at a single stroke.

Joint Euratom/U.S. R. and D.

At the same time the joint Euratom/USAEC Research and Development programme is receiving active promotion in spite of the fact that the two parties' statutory requirements have not yet been completed. Proposals have already been sought for projects either tied specifically to the reactors being built under the joint building programme (1,000 MW over the next 5-7 years) or of a more general and long-term nature. Funds available for the first half of the 10-year programme are expected to total about $100 million contributed in equal amounts by America and Euratom. Funds for the second period may be of the same order of magnitude.

A Joint Research and Development Board has been set up to consider proposals and preference will be given to schemes in which European and U.S. people work side by side on the same staff. Contractual arrangements may be of several types: payment of costs within prescribed limits; payment of such cost, plus a fixed fee; payment of a portion of the costs or a fixed sum; alternative suggestions will also be considered. Ordinarily contracts will be for a maximum of one year, but opportunity will be given to extend this period up to as much as five years.

Guidance has been given on the type of research and development most likely to receive favourable consideration. Considerable emphasis is placed on fuel element behaviour leading to burn-up figures in excess of 10,000 MWd/ton. For the most parts oxides and other ceramics of plutonium, thorium and uranium are indicated, but the behaviour of metallic uranium under irradiation is not to be neglected. Similarly a formidable programme of development in element fabrication techniques is envisaged. On the moderator side, the radio-chemistry of organics is slated to receive intensive study, including the influence of the presence of oxygen, hydrogen and water at various temperatures and encouragement will be given to a search for polymerization inhibitors. The organic moderated system is clearly believed to hold considerable promise and is expected to assume an important position in the power generation field.

This joint programme of research and development in both scale and scope is probably of much greater significance so far as the U.K. is concerned than is the common market. Tariffs have been set at a low level and should not materially prejudice the sale of U.K. equipment to Europe; other factors will carry much greater weight.

The R. and D. programme will allow a rapid build-up of expertise and know-how on the part of European industrial companies in the more advanced technologies. British companies have little opportunity of acquiring this sort of experience, the bulk of their effort being spent in competitive research into specific engineering problems, many of which are applicable only to the natural uranium graphite-moderated reactor. Experience in the broader field of reactor technology is, in the main, confined to a few members of the AEA and their consultants.

While Euratom and the U.S.A. forge ahead with their plans, the U.K. has spent months coming to a wholly milk-and-water agreement with Euratom, which

is now to be signed on Feb. 2. Chief point of argument has been the introduction of controls (to ensure peaceful uses only) and our attitude appears to have been conditioned predominantly by a highly theoretical military philosophy based on already out-of-date principles. A possible saving grace is that the agreement is officially described as a first step. Certainly it will do nothing to assist British exports and will not be as far-reaching on the development side as the present OEEC plans already operating. None the less, the delays and soft pedalling which have been characteristic of our discussions with Euratom, have hardened European resentment at Britain's insular attitude, resulting inevitably in increased sales resistance to British products.

From the longer term point of view, should we continue with our present policy, we could find ourselves in a situation which would be most uncomfortable commercially. Although we shall have been giving intensive development to a particular system, not only shall we have cut ourselves off from the market on our doorstep but we shall be faced in the more distant markets with competition from U.S.-European groups of considerable strength and with a background of broad industrial development experience which it will be difficult to match. In our further discussion with Euratom this picture must be kept in mind; Europe is not forced to come to Britain for her nuclear know-how.

Enrico Fermi Plant to Go Ahead

The opinions and initial decisions of the AEC concerning the propriety of continuing the permit granted to PRDC for the construction of the 100 MW(E) fast breeder reactor at Munroe, Michigan were made known during December of last year. Objections were first lodged by a number of trade unions soon after the granting of the initial permit in Aug., 1956. They claimed that the AEC had failed to satisfy itself on the safety of the plant (and on the financial competence of the company) taking the stand that an operational permit would follow automatically when the plant was complete. This view the AEC did not allow and pointed out that, not only were the two issues quite separate but it was self-evident that in any system new facts might be discovered which called for the recall of an operational permit even after a reactor had been operating for some years.

The fast breeder reactor (see *Nuclear Engineering*, March, 1957, p.112) is being engineered for PRDC by Atomic Power Development Ass. Inc. The Power Reactor Development Corp. which last summer concluded an information exchange agreement with the AEA is a non-profit making organization comprising public utilities and equipment manufacturers. Similarly, APDA is a non-profit making group, largely composed of the same companies; the president of Detroit Edison is president of both groups. APDA furnishes the design, technical services and the " component test facility," and will make extensive non-nuclear tests with it. The facility for practical purposes is the reactor with dummy fuel and one-third of the primary coolant loop. When the tests are complete it will be handed over to PRDC. The reactor, although based on EBR-1 experience, is significantly different in design, an important feature being the large sodium tank surrounding the core which provides a considerable thermal reservoir.

Emphasizing their distinction between operational and constructional permits, the AEC affirmed that PRDC had been on notice from the beginning that continuance of the plant was subject to further demonstration of many technological aspects including the complete safety of the reactor. The possibility of accidents cannot be categorically excluded and the concept of reasonable assurance of safety must be sensibly, although severely, applied. The Reactor Safeguards Committee indicated that, whilst there was no absolute guarantee that there would be no safety problems, construction should help to remove doubt and would provide a firmer foundation on which to base opinions. Certain questions still remain to be answered, but there was every reason to believe that a satisfactory solution would be forthcoming in time.

Sodium technology as such is considered reasonably advanced as the result of experience with EBR-1, SIR, SGR and satisfactory operation had been amply demonstrated. Critical aspects of stability concerned the observed positive temperature coefficient and resonance instability. The proposed experiments with the Mark III core in EBR-1 should definitely establish whether bowing is the cause of the first, and several methods of preventing this geometric distortion have been proposed. The second effect may result from series flow through the core and blanket, and again experiments on the Mark III core should provide an answer (the PRDC plant is designed for parallel flow). In addition Dounreay is scheduled for operation shortly and experience with this reactor should provide complementary evidence. At the same time construction is proceeding on EBR-2 and operational experience should give added confidence.

The necessity for building a prototype experimental reactor in a remote location first, cannot yet be ruled out, but it is the AEC's opinion that it is probable that evidence, forthcoming, will establish that the PRDC plant can be operated when it is completed.

This AEC evaluation must be regarded as an impartial, thorough examination by a group of top-line experts and their sober optimism concerning the reasonableness of operating the plant, when it is ready, says much for the advancement of knowledge in the fast reactor field, particularly when it is appreciated that the site is by no means " remote." We are, of course, still some distance from economic operation, but the safety aspects of the fast breeder system are looking more encouraging and the long-term prospects more hopeful.

DIGEST...

Surveying Significant News

Change in AEC Policy Forecast

A significant change in AEC's policy has been forecast by the *Wall Street Journal* which suggests that new plans are being made to concentrate future development work on five reactor types. Until now simultaneous development of many different reactor types has been the pattern. No plans have yet been made public but it is known that three types, the boiling water, organic moderated and gas-cooled will be retained with the fast breeder possibly as a fourth. Fifth place would probably be filled by one of the liquid fuel types. A notable omission is that of the pressurized water type but as advanced versions of this reactor are now similar to advanced boiling water reactors, this is understandable. This does not necessarily mean, however, that AEC will break existing commitments to study other proposals. They have in fact provisionally accepted proposals for a mercury-cooled fast breeder (American Radiator and Standard Sanitary), a modified sodium graphite reactor with modules containing fuel and coolant (General Electric) and a gas suspension coolant type (Babcock and Wilcox). Any major policy move is likely to meet with opposition from the Joint Congressional Committee, however.

CEGB 1958 Installed Capacity

Conforming with the policy decided upon in 1953 by the Government to give priority to export orders for power stations, the Central Electricity Generating Board's installed additional generating plant coming into operation in 1958 was smaller than in previous years. The total was 1,154,000 kW derived from 19 turbo-generators and 17 boilers installed in 16 power stations in England and Wales. Two of these stations were new.

European Insurance Decisions

Seventeen European countries, members of OEEC have now agreed to make third-party insurance, or other financial guarantees against third-party risks, compulsory for all nuclear installations. It has also been agreed that liability will be limited to 10 years from the date of an accident. And from Western Germany comes the news that insurance companies have promised to pay claims for damage resulting from the use of radioactive isotopes in machines insured by them.

IAEA Supplies Uranium to Japan

Following the request by the IAEA for tenders to supply natural uranium, and the Canadian gift of three tons, free of charge, IAEA have now set a price of $35.50/kg for their sale of 3,000 kg to Japan. It is interesting to note that of the tenders received last month, prices varied as much as from $54.34, United States, to $34.00, Belgium. It would now appear that the IAEA have set a reasonable price tag for natural uranium.

AEC, U^{233}, Pu Prices

AEC have now set their basic charges for uranium-233 at $15/g and plutonium $12/g for sale to private industry and foreign governments. In July, 1957, they agreed to pay, for the period lasting until July 1, 1962, $30 to $45/g for plutonium, in returned irradiated fuel, the price depending upon the isotopic composition. Over the next 12 months the figure was set at $30/g irrespective of grade but U.S. power plant designers have for some time been basing their economics calculations on a stabilized credit value of $12/g.

U.S. Hull for "Dreadnought"

No definite date has yet been fixed for the completion of the Anglo-U.S. agreement for the supply of a reactor to power "Dreadnought," Britain's proposed first nuclear-powered submarine. It has been revealed by the Admiralty, however, that "Dreadnought" will also have an American designed hull. Thirteen of the new reactors started on in 1958 in the U.S. are for submarine propulsion and the latest to be launched, the U.S.S. "Halibut," is capable of firing nuclear missiles.

HAR Power Demonstration Reactor Abandoned

The decision by Westinghouse Electric and Pennsylvania Power and Light to drop, for the time being, all plans to build a large-scale HAR nuclear power plant, was not unexpected. The estimated cost to the companies and AEC of $108 million is regarded as being exorbitant for the value of the project. The two companies originally proposed, at the invitation of AEC, to build plants of this type in Jan. 1957. This was shortly after the experimental HRE-2 reactor achieved criticality at Oak Ridge. In April, however, a serious leak was discovered in the core container and the reactor is now operating as a single-zone system at 5 MW. Plans to stop work on the U.K. project of this type were announced early in the summer of last year.

IAEA Plan Five International Conferences

IAEA will hold five scientific meetings on some aspects of the peaceful uses of nuclear energy this year. The first will be a three-day seminar in Vienna, from February 25, on medical radioisotopes scanning. Then in July a seminar on the training of specialists in the peaceful uses of atomic energy will be held at Saclay, France, and a six-day conference on the application of large radiation sources in industry is scheduled for Warsaw for September. Standardization of radioisotopes will be discussed in Vienna in October and the last of the series on the disposal of radioactive wastes will be held in Monaco in November.

U.S. Reactor Progress

According to a report issued by the Atomic Industrial Forum, the United States, during 1958, completed 37 nuclear reactors at home and abroad, and began building 45, which is a creditable achievement. In addition, eight new uranium ore mills were completed and at least 39 particle accelerators sold.

AEC Promotes Radioisotope Exploitation

The AEC, it appears, are fully aware of the growing demand for more trained technicians in radioisotope technology and facilities for training. They have now announced a new programme of assistance which will mean that colleges and universities will be allowed direct financial assistance in obtaining equipment.

Extension of U.K.-German Agreement?

An early signing of an agreement between Western Germany and the U.K., removing all obstacles to the delivery of British nuclear plants, can now be expected. The agreement signed in 1956 which enabled A.E.I.-John Thompson to start building a Merlin reactor for the North Rhine-Westphalia State Government, and a DIDO reactor, built by German companies to designs of Head Wrightson Processes, could be enlarged upon. Latest news on the requirements for nuclear power in the country come in the form of tenders sought from British, French and American firms for a 150 to 250 MW plant for R.W.E., the largest electricity company in West Germany.

U.S.S.R. Authorizes Use of Irradiated Potatoes

In a speech to the Farmers Club on Dec. 9, Sir John Cockcroft made reference to the fact that, following an investigation by the Nutrition Institute of the U.S.S.R. Academy of Sciences, the use of irradiated potatoes for general consumption had been approved in the U.S.S.R. Sprouting of potatoes can be delayed for periods up to eighteen months and the irradiated tubers are not affected in flavour. Large-scale feeding trials have been under way in the West on animals to ensure that no harmful substances are produced during the sterilization.

French Nuclear Sub. will use Enriched Uranium

France's projected nuclear propelled submarine "Q-244" will initially be fuelled by U.S. enriched uranium. In a lecture to the Academie des Sciences on January 6, M. Francis Perrin, High Commissioner for Atomic Energy stated that the initial intention had been to build a natural uranium fuelled reactor, but recent amendments made to the U.S. Atomic Energy Act made this unnecessary. Furthermore, domestic fuel would become available in a few years' time following the French Government's decision to build a diffusion plant. Whether this will be a national project or will involve Euratom has still to be made clear.

Reactor Briefs

The Special Power Excursion Reactor—SPERT 3—situated at the National Reactor Testing Station, Idaho Falls, achieved criticality on Dec. 20. . . . University of Frankfurt's solution-type research reactor has reached full design power of 50 kW. . . . BRR, a reactor for medical research, is part of the equipment of a medical research centre dedicated recently at Brookhaven National Laboratory.

Gas-Lubricated Bearings in Nuclear Engineering

By D. PANTALL, A.M.I.Mech.E. and C. H. ROBINSON

The theoretical and practical differences between bearings lubricated by liquids and gases are examined with particular reference to the hydrodynamic type. Pressure-fed bearings will form the subject of a subsequent article.

THE exacting demands of nuclear engineering have led to an intensified study of lubrication by gases arising, initially, from the need for leak-proof gas circulators for use in reactor loops, and interest is now centred on the use of gas bearings for reactor coolant circulators. Other applications include hermetically sealed pumps for liquid metals and organics (pumped loop experiments were able to commence much earlier than would have otherwise been possible) and remote handling equipment where advantage is taken of reduced friction. Gas bearings have been applied to both high and low temperature equipment.

Types of Bearing

As with oil lubrication, there are two main categories of gas bearing, the self-acting (hydrodynamic) and the pressure fed (hydrostatic). The former is self-contained but has a load-carrying capacity which is limited and speed-dependent, while the pressure-fed bearing requires a gas supply, the pressure of which determines, independently of speed, the load that can be carried. The self-acting bearing has received the most attention in the nuclear engineering field, but it may be expected that the pressure-fed types will receive more, as bearing loads are increased.

The two types may be combined in a single bearing, the pressure feed being used to give support during starting and stopping conditions, support during rotation being obtained solely from the hydrodynamic action.

SELF ACTING (HYDRODYNAMIC) TYPE

Designs similar in principle to those developed for oil lubrication have proved successful with gas lubrication. For thrust bearings these comprise the pivoted or tilting pad, the fixed or tapered land and the hydrodynamic pocket. In addition, the viscosity groove type which has a number of narrow, shallow spiral grooves cut into its surface has proved successful. Similar types, as well as the plain sleeve, are used for journal bearings.

Differences from Oil Bearings

The principal difference between gas and liquid lubrication arises from the compressibility of the gas. If the pressures generated within the bearing clearance by hydrodynamic action are markedly different from the ambient pressure, then the gas density will also vary. The initial derivation of the equation for the pressure distribution around the bearing is the same as for liquid lubrication, but in solving this equation the density can no longer be assumed to be constant and has to be treated as a variable. To solve the pressure distribution equation, the relationship between pressure and density must be known. The simplest relationship is an isothermal one but even so the resulting non-linear differential equation cannot be solved exactly. Compressibility effects are only of importance if the pressure changes within the bearing clearance are large compared with the ambient pressure (Fig. 1). Ambient pressure must also be considered as a variable and this leads to a grouping of the parameters which is different from that found in liquid lubrication.

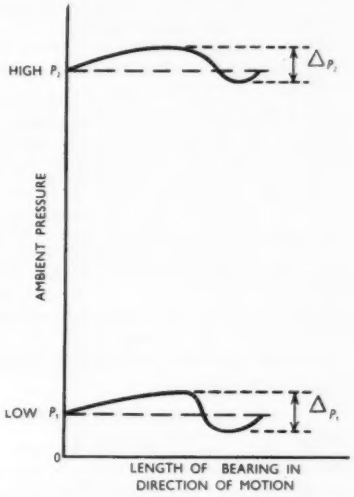


Fig. 1.—Effect of ambient pressure showing relative effects of compressibility which are insignificant at high values of ambient pressure but significant at low values (constant bearing geometry, speed and load assumed).

The load-carrying capacity of any hydrodynamic bearing, neglecting compression effects, is directly proportional to the viscosity of the lubricant. Thus the load-carrying capacity of a gas bearing will be perhaps a thousandth of that of an oil bearing of the same size. This leads to a number of distinctive design features. The size, for example, is inevitably large relative to other components, since the static weight of rotating parts which can be carried on journals is approximately 1-2 lb/in.^{2} (projected area). Also, the journal length tends to be greater than the diameter, in order to reduce end leakage.

Accuracy of manufacture must be of as high a standard as practicable, in order to permit worthwhile operating eccentricities and still maintain an unruptured gas film. The absence of boundary lubrication precludes "running in," and the bearings must therefore be made to the final desired accuracy before assembly. Under certain conditions, some metal-to-metal rubbing can be tolerated for short periods, but absolutely no reliance can be placed on this for design purposes. For this reason, some self-aligning device will, usually, be provided where a shaft runs in two journal bearings. Similarly thrust bearings will normally be self-aligning.

If the bearings are operating on a condensible vapour then under certain conditions the vapour might condense

within the bearing clearance. The effects of this have been discussed by Ford *et al.*

Viscosity-Temperature relationship. Most oils have a viscosity which sharply decreases with increase of temperature and the working temperature range is limited. In contrast, the viscosity of most gases increases slightly with temperature and the working temperature range is much greater.

Journal Design Considerations

Usually, the choice will lie between the pad and full plain bearings, both of which have similar load-carrying capacities. The former is much more difficult to make but has the very great advantage that it is free from the half speed film whirl instability which affects the full journal bearing. Generally, the full plain bearing is to be preferred because of its simplicity and the design information available; it will therefore be the only type considered.

NOMENCLATURE

a	Shaft radius.
c	Mean value of radial clearance between shaft and journal bearing.
D	Shaft diameter.
G	Non-dimensional group $6\mu Ua/c^2p_a$ for journal bearings.
h_{min}	Minimum clearance in journal bearings.
l	Length of journal bearings.
L	Load carried by journal bearing.
n	Fraction eccentricity of a shaft in a bearing shell, i.e. displacement of centres/mean radial clearance.
N	Speed of rotation, revolutions per minute.
p_a	Ambient pressure surrounding the bearing.
U	Velocity of moving surface of bearing pair.
W	Non-dimensional load group, L/lap_a.
μ	Viscosity.

For the full journal bearing the following relationship may be derived:

$$W=G\,f(n) \text{ (neglecting end leakage)}$$

where $W=L/lap_a$

and

$$G=6\mu Ua/c^2p_a$$

Typical relationships are shown in Fig 2. It should be noted that at high volumes of G (i.e., considerably greater than 10) compressibility effects have become dominant and the load becomes independent of speed and viscosity but dependent only on ambient pressure.

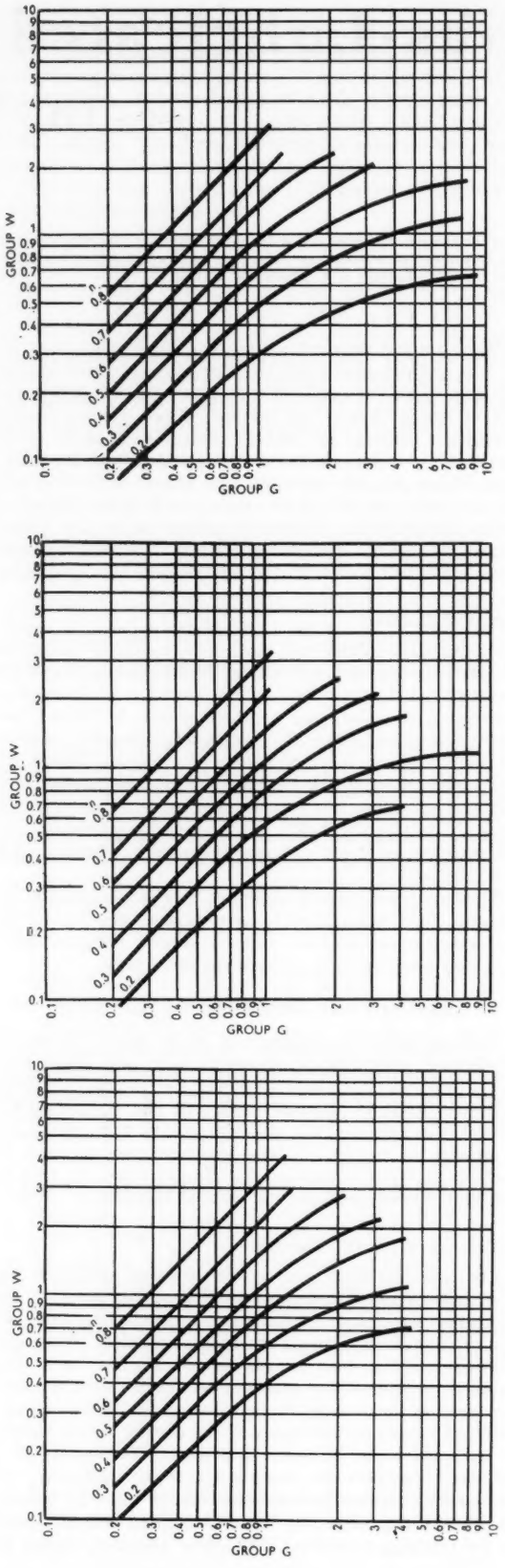


Fig. 2.—Non-dimensional grouping of parameters for full journal bearing. (Top) $l/a=4$; (middle) $l/a=5$; (bottom) $l/a=6$.

Load Calculations

The load which a given bearing will carry can be predicted from a theoretical analysis, or from experimental data. For the theoretical analysis to be of use it must allow for end leakage effects, for the gas compression and most important of all be proven by experiment. Useful design charts have been given by Ford *et al.* and by Ausman. The former is derived wholly from experimental results while the latter is based partially on theory and partially on experiment. Both use basically the same four groups of parameters G, W, l/a, n; Fig. 2 is based on the chart of Ford *et al.* It is therefore desirable at this stage to discuss the practical significance of these groups. Some of the considerations are of course similar to those involved with liquid lubrication.

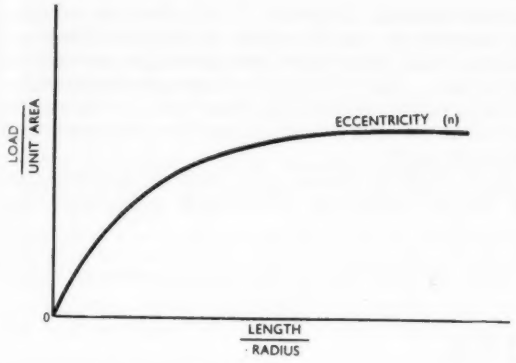
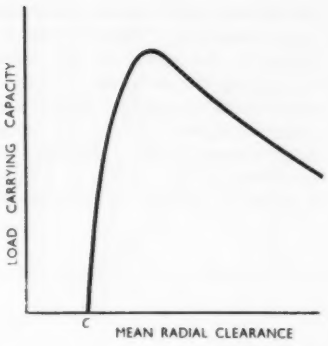


Fig. 3.—(Left) Effect of length/radius ratio on load-carrying capacity of full journal bearing.

Fig. 4.—(Right) Optimum value of mean radial clearance for full journal bearing.



The Length-Radius Ratio l/a

The importance of this group is shown in Fig. 3. The load carried per unit area is proportional to length for the shorter bearing while for a long bearing it is independent of length so that to make efficient use of the bearing area, it is desirable to make the bearing as long as possible, although the length chosen will also depend on more immediate practical considerations. The short bearing is very weak to loads resulting from bearing mis-alignment, the long bearing is more difficult to make to the required accuracy besides tending to make for a long shaft. Ford *et al.* recommend a length-radius ratio of 4-6.

The Eccentricity Ratio n

If all other things remain unaltered then the larger the eccentricity the greater the load carried. Thus for a given mean radial clearance the maximum load which can be carried will depend on the minimum clearance to be permitted which in turn depends on the accuracy to which the bearing surfaces are made and allowing a margin as safety factor. This minimum permissible value of minimum clearance may be stated as:

$$h_{\min} = x + D \times 10^{-4}$$

where x is the variation (inches) in diameter of bearing or shaft. For a 2-in. shaft, for example, with a diameter constant to within 0.0001 in., the minimum clearance would be 0.0003 in. The importance of a high standard of dimensional accuracy is thus apparent. Compared with this, surface finish is of much less importance; that resulting from the final precision grinding or honing operation necessary to achieve geometric accuracy is entirely adequate.

The Load Group $W = L/lap_a$

This is a measure of the load carried per unit projected area, with the addition of a term to take account of ambient pressure.

Remaining Terms $G = 6\mu\ Ua/c^2p_a$

This embraces the remaining parameters speed, clearance and viscosity as well as radius and ambient pressure. From the discussion on eccentricity it would, at first sight, seem desirable to have a large mean radial clearance thus permitting a large eccentricity value. However, as the clearance increases the load carried for a constant eccentricity decreases due to a reduction in viscous shearing forces. Increasing the clearance also increases the tendency towards " half speed film whirl " instability. The friction is also somewhat reduced by increasing the clearance, but for practical purposes this will be of no consequence. Taking into account the minimum permissible clearance previously mentioned, there is an optimum value of minimum clearance which gives the maximum value of load that can be carried. (See Fig. 4.)

The difference in viscosity of gases likely to be used as a lubricant is small. Because gas viscosity increases with temperature, if the bearing is to work above room temperatures it is often convenient to ignore the viscosity increase as testing will be done at room temperature. If the bearing is to work below room temperature, however, then the decrease in viscosity must be taken into account.

Increase of speed increases the load that can be carried. The rate of increase falls off at high speed due to compressibility effects, although the major part of the load to be carried at high speeds is increasing with the square of the speed. (See Fig. 5.)

The value of G clearly shows if the gas is acting as a compressible lubricant or not. If G is much greater than unity then compressibility effects are becoming prominent and under these conditions load-carrying capacity becomes independent of viscosity and speed but does become dependent on ambient pressure.

Selection of Values

When designing a journal bearing, speed, viscosity and ambient pressure are usually fixed by considerations other than those of bearing design leaving length, radius, clearance and eccentricity to the choice of the bearing designer. The relationship between length and radius has already been discussed. A first estimate of these two parameters is usually provided from a consideration of the sizes of other components in the finished machine, e.g., motor dimensions and shaft stiffness. A provisional estimate of clearance may then be made by assuming a value of 0.0003 in./in. of shaft diameter as suggested by Ford *et al.* The maximum eccentricity to be permitted can then be fixed as indicated previously. Thus groups l/a, G, and n can now be calculated enabling the remaining group W to be found from the design charts previously referred to. Since l, a, and p_a have already been fixed the load to be carried will indicate if adjustments to the length or radius have to be made.

Applied Loads

In addition to the static weight of the rotating parts there are other loads which must be taken into account because in many cases they can greatly exceed the static weight load. Some of these are:

Residual out-of-balance load. Accuracy of dynamic balance must be known.

Synchronous whirl load. Due to the residual out-of-

balance the shaft centre rotates about the bearing centre (approximately). There is thus a dynamic load proportional to the radius of this rotation. The magnitude of this can be obtained, for example, from a successive approximation method whereby the out-of-balance and static loads are fed into the design charts and the shaft displacement found. This may be used to calculate the synchronous whirl load, to a first approximation, which is added to the out-of-balance and static loads and the process repeated. However, it will often be sufficient or expedient to use the value of minimum clearance adopted when determining the maximum permissible eccentricity. This will give the largest permissible value of the synchronous whirl load and hence by adding the out-of-balance load and static load the maximum total calculable loads.

Static weight of rotating parts. It should be noted that the out-of-balance and synchronous whirl loads are

APPENDIX

TABLE 1

Advantages of Gas Bearings for Various Application Requirements

Requirement	Advantages over oil bearings
1. Negligible leakage ..	(a) Elimination of shaft seals, which are especially difficult for high pressures, high temperatures and high rotational speeds. Therefore: (b) Gas purity maintained. (c) No leakage of radioactive particles. (d) No make-up gas required. (e) Simplicity. (f) Reliability and long life.
2. Low-temperature operation.	Simplicity because of: (a) Elimination of shaft seals. (See 1(a).) (b) Difficulty, if not impossibility, of obtaining suitable liquid lubricants.
3. High-temperature operation.	See 1(a) and 2(b). Oil viscosities are very temperature-dependent and are stable only up to relatively low temperatures.
4. Low friction ..	Simplicity if bearing already in gas atmosphere, because no liquid to dispose of or to cause contamination.
5. Small pumps for high-temperature liquid metals or organic liquids.	(a) Some liquids are difficult or impossible to pump by electro-magnetic pumps. (b) One motor drive unit comprising bearings and motor will do for any liquid and can be tested quite independent of liquid. (c) Motor insulation well away from high temperatures. (d) Gas space suitable for removing gaseous fission products and acting as surge volume. Note: Apart from the general limitations of gas bearings (see Table 4), this application has the added disadvantage of the need to reduce gas entrainment in the liquid and precautions to be taken if the liquid has a high vapour pressure.
6. High speeds and long life.	(a) Elimination of shaft seals. (See 1(a).) (b) Cooling problems simpler.
7. Operation in radiation fields.	(a) Many oils polymerize under irradiation. (b) Life of rubber diaphragms very short.

TABLE 2

Comparison of Self-acting and Pressure-fed Types

Factor	Self-acting	Pressure-fed
Gas compressibility.	Starts to decrease bearing strength as unit applied load becomes large (say 10%) compared to the absolute ambient pressure.	Effect is a very minor one.
Speed and viscosity.	Strength dependent unless compressibility affecting performance, then tends to become independent.	Strength relatively independent: there may be a small gain in strength.
Gas supply pressure.	Strength independent ..	Strength dependent.
Ambient pressure.	Strength independent unless compressibility affecting performance, then tends to become dependent.	Strength independent.
Load capacity..	Low; effectively about 1 to 3 pounds static load per square inch of unit projected area.	Limited only by supply pressure available.
Starting friction.	Metal-to-metal contact at start up.	Friction in gas film only.
Materials ..	Limited to those with good anti-galling properties.	Unlimited.
Instabilities ..	Only those originating in the gas film.	The arrangement of the gas inlet may cause instabilities in addition to those originating in the gas film.
Manufacture ..	Tolerances and finishes are more stringent than those encountered in conventional bearing practice.	Standard machining techniques will give satisfactory operation.
Running costs.	No external running costs are involved.	Cost of compressor pumping power must be allowed for.
Size	Relatively large. (See "load carrying capacity.")	May be much smaller if sufficient supply pressure available.

TABLE 3

Respective Fields of Application of Basic Bearing Types

Self-acting	Pressure-fed
Light loading and continuous operation.	Low or zero speeds
	High unit loading, e.g. for limited space.
Hermetically sealed machines in which inward and outward leakage is an embarrassment or cannot be tolerated.	Very low ambient temperature operation where the low gas viscosities tend to make self-acting bearings impracticably large.
Economy and simplicity of operation —e.g. zero external gas supply.	For operation over a large temperature range.
	Given a suitable feed-back link between load and supply pressure, a system can be arranged to have constant shaft location independent of load without involving extremely fine clearances.
	Fluctuating loads.

TABLE 4

Disadvantages Compared with Oil Bearings

Factor	Self-acting	Pressure-fed
Load capacity..	Very much lower (about 1–1,000), due to the difference in viscosities.	Much lower since no pockets can be used with compressible fluids.
Pumping power.	—	Higher because of compressibility.
Boundary lubrication.	None. Therefore useable materials limited and more costly.	None. Therefore use as overload protection not possible.
Design standard.	Very precise control of design is required.	Design standards need be little different.
Machining ..	Very much higher standards required.	Standards need be little better.
Cleanliness ..	High standard in assembly essential.	Standards need be little different.
Instabilities ..	More likely to occur.	More likely to occur.

proportional to this. Thus any reduction will have a powerful influence in reducing shaft and bearing size.

Mis-alignment loads and electrical loads. Depend on accuracy of manufacture.

Safety Factor

After consideration of the bearing strength and applied loads there arises the question of the correlation between the two, which must to some extent depend upon experience. For single-bearing machines the initial correlation may be fairly exact, but for two-bearing machines a much greater allowance has to be made to allow for mis-alignment. Ford *et al.* say that the applied load should not be greater than one third of the bearing strength.

Distribution of Mass

It is desirable in a two-bearing machine that the majority of the total rotating weight should lie between the bearing centres, or within the bearing in the case of a single-bearing machine, otherwise the axial pressure distribution within the bearing clearance may be so distorted that failure will occur.

Half Speed Film Whirl

Instabilities, generally termed " oil film whirls " are sometimes encountered in oil lubricated full journal bearings. In the corresponding gas bearing " half speed film whirl " to which previous reference has been made, the usual mode is that the shaft centre rotates about some point near the bearing centre at approximately half the shaft speed, and is disastrous to the operation of the bearing. To show why this is so there is a much simplified qualitative explanation as follows:

In a self-acting bearing the lift is produced by the differential shearing of the fluid as it is squeezed between the converging surfaces of the bearing. The average speed of the gas is about one-half the speed of the moving surface. If now the position of the wedge formed between the moving and fixed surfaces also moves in the direction of the fluid at the average speed of the fluid, no lift-producing action can occur. This motion of the shaft centre about the bearing centre at about half shaft speed, which produces the same effect, destroys the action of the bearing.

If the bearings are mounted in self-aligning mountings these too can take up a conical half-speed whirl motion, which may or may not be associated with a shaft motion depending upon the constraints.

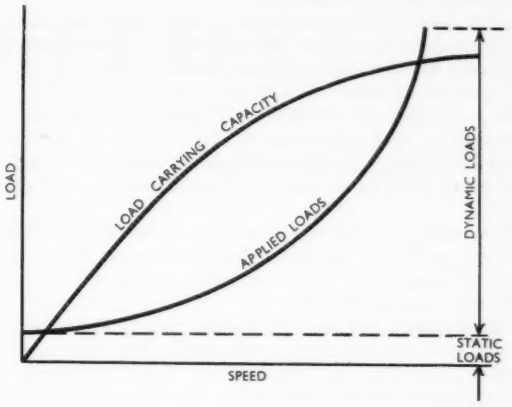
There is practically no useful design information published concerning the phenomena of half speed film whirl. The main lines of defence seem to be:

1. Keep mean clearances as small as possible.
2. Design the bearing for as high a unit loading as permissible.
3. Keep the speed as low as possible.

Remedial action, apart from the preceding factors, is similar to that used in oil bearings. A groove in the low-pressure region of the bearing, as described by Ford *et al.*, raises the onset speed somewhat and can be very effective if pressurized. A similar cure is the provision of stabilizing pockets described by Drescher. A complete alternative is to dispense altogether with the full journal and use instead the preloaded multiple pad type, or the stepped bearing, neither of which is prone to half speed film whirl.

It should be noted that the term " film whirl " is used to distinguish it from the more well-known shaft whirl which is quite different and for self-acting gas bearings normally bears no relationship.

Fig. 5.—Effect of speed on loads for full journal bearing.



Mountings

This applies to shafts mounted in two-journal bearings. Methods that are used include the machining *in situ* technique, spherical seatings, diaphragm supports and gimbal supports.

Materials

The choice of materials depends on three properties. Anti-galling is one, and materials used have been chrome plate, S-Monel, meehanite, carbon and tungsten carbide. With these combinations many thousands of starts and stops have been reported. Anti-corrosion properties are often merely a matter of anti-rusting but may be connected with the particular working gas. A third important factor is the thermal expansion properties.

Starting

The attainment of a continuous gas film around the shaft is a necessary condition. If many starts and stops are required, bearing in mind that there is no boundary lubrication, the start-up period should be as short as possible to reduce the rubbing time. This method is only applicable to small machines where the extra torque necessary for fast starting is comparatively easy to provide.

Auxiliary methods that have been employed are the use of jacking gas, and the injection of volatile liquids. Magnetic devices have also been suggested.

Cooling

Precautions must be taken to minimize distortion and differential expansion of shaft and journal bearing. Increase in temperature of the lubricating gas is of minor significance since the viscosity increases with temperature, but differential expansion is of major importance since the resulting mean clearance change will affect the bearing performance.

Thrust Bearings

The three main types of thrust bearing have already been mentioned—pad, pocket and grooved. The choice will depend on the relative merits of ease of manufacture, ease of installation and load capacity. The pad bearing is inherently self-aligning, whereas the other types usually require self-aligning mountings. Machining is probably simplest for the grooved type. The surfaces of all types must be made very flat and the pocket and groove types then require the cutting of the grooves or pockets. For most cases, except high speeds and low ambient pressures, compressibility effects in thrust bearings can be ignored so that in the case of the pad and pocket bearings oil

bearing data may be used. For the grooved bearing Ford *et al.* give a design chart.

Some idea of the comparative load capacities can be obtained using as a basis of comparison a pocket bearing described by Drescher, with an inside diameter of 2.1 in. and outside diameter of 3.37 in., running at 2,870 r.p.m. with a clearance of 0.000256 in. Drescher's pocket bearing sustained a load of about 5 lb. Using an equation given by Fuller, a similar pad bearing would carry 8.5 lb and using Ford *et al.* data a grooved bearing will carry 9 lb.

The loads to be carried by a thrust bearing on a blower will be made up of static loads, impeller loads, and electrical loads, due to the magnetic centre of the rotor and stator being displaced.

The thickness and support of the bearing must be such that there is no distortion of the surface from the bending moments imposed by the load or from the result of temperature gradients within the bearing.

Materials and starting considerations are similar to those for journal bearings.

Manufacture

The required accuracy of manufacture is related to the design philosophy. If small mean radial clearances and large operating eccentricities are specified, a very high standard of accuracy will be required. Whenever possible it is preferable to determine first the manufacturing accuracy that is reasonably attainable, and base the design philosophy on this. It should be noted that the emphasis must be on accuracy of parallelism, roundness and straightness rather than on surface finish. This emphasis is not always readily apparent when looking at components since usually in obtaining good geometry a good finish also results. Accuracy and thoroughness of inspection is essential. Careful assembly is also essential to ensure that no distortion is introduced.

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Paliers Lubrifiés au Gaz

La lubrification des paliers au gaz au lieu de l'huile est très pratique pour les compresseurs, souffleurs, pompes, etc., pour lesquels on recherche une fermeture hermétique. On emploie des modèles tant automatiques (hydrodynamiques) qu'hydrostatiques alimentés sous pression. Un grand nombre de problèmes de conception se posent, vu que la capacité de transport de charge d'un palier au gaz est toujours de beaucoup inférieure à celle d'un palier à l'huile, par suite des différences de viscosité du lubrifiant. La fabrication en est difficile par suite de la nécessité de prévoir des distances libres extrêmement fines.

Le présent article passe en revue les considérations de conception et les paramètres généraux tant pour les coussinets que pour les paliers de butée.

Gas-geschmierte Lager

Die Schmierungen von Lagern mit Gas anstatt mit Oel ist besonders zweckmässig für Kompressoren, Gebläse, Pumpen usw., wo hermetische Abdichtung verlangt wird. Man verwendet sowohl selbstdichtende (hydrodynamische), als auch unter äusserem Druck arbeitende (hydrostatische) Lager-Typen. Bei der Konstruktion treten zahlreiche Probleme auf, da die Belastungsmöglichkeit eines gasgeschmierten Lagers immer sehr viel geringer ist als die eines ölgeschmierten Lagers, was durch den Unterschied in der Viskosität bedingt ist. Weiter ist die Herstellung erschwert wegen der erforderlichen ausserordentlich geringen Toleranzen.

Der Aufsatz beschäftigt sich mit den allgemeinen Parametern und den Konstruktions-Grundlagen sowohl für Gleitlager als auch für Endlager.

Cojinetes Lubrificados con Gas

La lubrificación de cojinetes con gas en lugar de con aceite es muy conveniente para compresores, sopladores, bombas, etc., donde se necesita sellado hermético. Se emplean tanto los del tipo autoactuante (hidrodinámico) como los del tipo hidrostático alimentado a presión. Existen muchos problemas de diseño, desde la capacidad portadora de carga de un cojinete lubrificado con gas es siempre mucho menor que la de un cojinete lubrificado con aceite, debido a las diferencias de viscosidad del lubrificante. La fabricación es difícil debido a los espacios libres extremamente reducidos que son necesarios.

Este artículo examina los parámetros generales y las consideraciones de diseño para cojinetes tanto del tipo con muñón como del tipo de empuje.

Liquid Metals (pages 59-63)

Métaux Liquides

Il se pourrait que les Métaux Liquides deviennent les seuls réfrigérants pratiques pour les réacteurs rapides ou, en fait, pour tous les réacteurs dans lesquels un petit noyau a un taux de chaleur très élevé. Normalement, ils tombent dans deux catégories, la première comprenant le sodium, le potassium et leurs alliages employés comme réfrigérants seulement, et la seconde renfermant le bismuth et ses alliages qui s'emploient là où le combustible lui-même est dissous dans le réfrigérant.

Cet article passe en revue les propriétés chimiques et physiques du sodium, potassium, NaK, bismuth et mercure, vu que ce dernier s'employait aux débuts. Une partie considérable de l'article est consacrée à la compatibilité avec les autres métaux et avec le graphite et la céramique; on y traite aussi des mesures de protection.

Flüssige Metalle

Wahrscheinlich werden flüssige Metalle mit der Zeit als die einzig praktischen Kühlmittel für schnelle Reaktoren oder überhaupt für alle Reaktoren angesehen werden, bei denen ein kleiner Kern mit einer sehr grossen Wärmeerzeugung verwendet wird. Die Metalle fallen normal unter zwei Kategorien, nämlich Natrium, Kalium und ihre Legierungen, die nur als reine Kühlmittel dienen, und Wismut und seine Legierungen, die dort verwendet werden, wo der Brennstoff selbst im Kühlmittel gelöst ist.

Der Artikel enthält Angaben über die chemischen und physikalischen Eigenschaften von Natrium, Kalium, NaK, Wismut und Quecksilber, da dies letztere bei früheren Arbeiten auch benutzt wurde. Ein beträchtlicher Teil des Artikels ist der Frage gewidmet, wieweit sich diese Kühlmittel mit anderen Metallen und mit Graphit und keramischen Materialien vertragen. Sicherheitsvorkehrungen werden ebenfalls besprochen.

Metales Liquidos

La tendencia actual es en el sentido de que los metales líquidos vayan a volverse los únicos refrigerantes prácticos para reactores rápidos o, en efecto, para todos los reactores en los cuales un pequeño núcleo posee un régimen de calor muy elevado. Normalmente caen en dos sistemas: sodio, potasio y sus aleaciones empleados únicamente como refrigerantes, y bismuto y sus aleaciones, que se emplean donde el combustible mismo se disuelve en el refrigerante.

Este artículo considera las propiedades químicas y físicas del sodio, potasio, NaK, bismuto y mercurio, desde que este último fué usado en trabajos al principio. Una parte considerable del artículo se dedica a la compatibilidad con otros metales y con grafito y material cerámico. También se incluyen las precauciones de seguridad.

LIQUID METALS

By J. W. EVANS B.Sc., Ph.D.
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This article presents in a convenient form the properties and individual characteristics of the liquid metals suitable for reactor coolants.

THE excellent heat transfer properties of liquid metals have contributed largely to their consideration and intensive development as reactor coolants. Because of their generally high boiling points they can be used at high temperatures with only moderate pressures. They do not undergo structural changes under irradiation although they may give rise to undesirable radioactive isotopes in certain cases. Liquid metals are likely to become the only practical coolants for fast neutron reactors employing highly enriched uranium or other fissile material in which the heat rating is high and the fuel is contained within a relatively small core.

There is an extensive literature on liquid metals; a very full account of the physical and chemical properties of a wide range of liquid metals with a number of actual and proposed industrial uses (excluding nuclear) is given in the Liquid Metals Handbook[1]; a large supplement[2] deals exclusively with sodium and sodium-potassium (NaK) alloys, mainly concerning nuclear applications.

Whilst a number of liquid metals have potential uses as general heat transfer agents, it now seems fairly clear that there are only two principal systems under large-scale consideration for reactors. The first concerns the use of sodium and its alloys with potassium in which the liquid metal is used purely for heat transfer from a canned fuel. The second concerns bismuth (or bismuth alloy), in which the liquid metal is not only a heat-transfer medium but contains the fuel dissolved in it. This second system has been also considered for a " breeder " blanket in which a thorium-bismuth slurry suspended in bismuth would surround the main liquid metal circuit and allow excess neutrons to be absorbed by the thorium, thus generating fissile U^{233}.

Mercury has also been included, since pioneer work on corrosion was done in this system and it was the first liquid metal to be used as a primary reactor coolant.

In general, the production and handling of these materials present no special difficulty and a variety of electromagnetic and mechanical pumps have been successfully developed for high-speed circulation. Nevertheless, the metallurgical problems of corrosion and mass transfer in flowing metal systems are by no means completely solved, although intensive research has been carried out. Quite apart from engineering design, the selection and development of materials for use in liquid metal circuits are major problems[24].

Occurrence and Production

Mercury occurs principally as the sulphide ore cinnabar (HgS) from which the metal is readily obtained by oxidation and distillation. It may be purified to a high degree by repeated distillation and treatment with dilute nitric acid to remove traces of base metals. The world's main supplies are from Italy, Spain and the U.S.A.

Both sodium and potassium are produced by the well-known process of electrolysis of the fused chlorides. Sodium-potassium alloys may be made by mixing and melting together the separate metals or by reacting sodium with potassium chloride. The common and most serious impurity is dissolved oxygen, which is difficult to exclude during handling, although it can be minimized by filtering and blanketing the metal with argon during transport from the electrolytic cell to the container. The importance of oxygen will be discussed fully later.

Bismuth is extracted from relatively rich oxide and sulphide ores as well as from copper and lead smelting residues. Peru is the chief supplier; it is also produced by a number of base-metal smelters in North America. The sulphide ore is readily reduced by metallic iron and suitable fluxes are added to produce a slag to remove oxide impurities. Refining is mainly carried out by liquation and melting with fluxes to selectively oxidize impurities. Metal of 99.95% purity is commercially available.

Physical Properties

Fairly complete and reliable data on the physical properties of mercury, bismuth, sodium and potassium exist. The majority of values have been taken from the Liquid Metals Handbooks[1, 2]. Many data are presented which are useful in heat transfer calculations.

With the usual heat transfer fluids, the thermal conductivity of the medium is relatively unimportant when heat is transferred by turbulent mixing. However, with liquid metals, their high thermal conductivity contributes significantly to heat transfer under such conditions and, understandably, the usual equations relative to convective heat transfer do not apply. See, for example, accounts given by Lyon and Poppendiek[3] and Hall[4]. Furthermore, it follows that surface wetting of pipework and the existence of thin corrosion films can both play a more significant rôle in heat transfer with liquid metals than with other fluids. An important parameter is the Prandtl number, which is the product of the specific heat and viscosity divided by the thermal conductivity. Some typical values (Table 1), calculated from the data, show that liquid metals are characterized by small Prandtl numbers.

TABLE 1. Prandtl Numbers of Liquid Metals

Metal and temp.	Prandtl No.
Mercury (250°C)	0.0095
Bismuth (500°C)	0.012
Sodium (600°C)	0.004
Potassium (600°C)	0.003
78K–22Na_2 (400°C)	0.007
H_2O (liquid 300°C)	1.02
CO_2 (1 atm. 400°C)	0.75

Nuclear Properties

Bismuth has a desirably low cross-section for thermal neutrons whilst sodium and potassium have moderate

cross-sections. Mercury, however, has a high cross-section but this does not preclude its use in highly enriched reactors or, of course, in a secondary heat exchanger circuit.

Under irradiation sodium gives rise to Na^{24} by neutron capture. This is a hard gamma emitter, and has a half-life of 15 hours, which is sufficiently long to give restricted access to equipment and pipework in contact with irradiated sodium, as well as requiring extensive shielding during use. Under irradiation, bismuth produces polonium which is considerably more toxic than plutonium.

Melting Point

Sodium, potassium and bismuth are solids at room temperature. An attractive feature of sodium-potassium is that there is a range of alloys that is liquid at normal temperatures, e.g., the eutectic composition 22% Na, 78% K has a m.p. of −11°C. The liquidus curve for sodium-potassium is shown in Fig. 1.

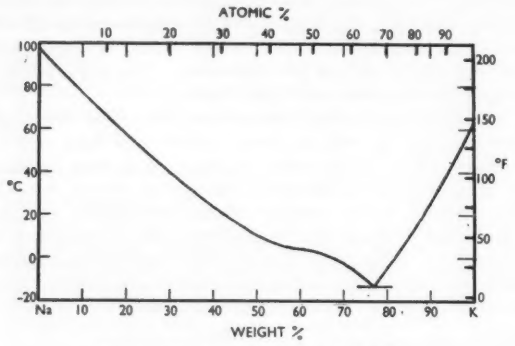


Fig. 1.—Liquidus curve for Na-K (18).

Lead and tin additions to bismuth give lower liquid temperatures but none are liquid at room temperature.

Vapour Pressure and Boiling Point

With the possible exception of mercury (b.p. 357°C) the metals have sufficiently high boiling points to make pressurizing unnecessary at possible reactor temperatures of 500°-600°C. The vapour pressures of sodium and potassium are, however, sufficiently high at these temperatures for ignition to occur should the hot metal come accidentally into contact with air. This fire hazard is discussed later.

Expansion and Volume Change

Exceptionally, bismuth expands on solidification; the lead-bismuth eutectic composition (44.5% Pb, 55.5% Bi) does not change volume at the freezing point.

Surface Tension

In general, liquid metals have relatively high values for surface tension and frequently do not wet solid metal surfaces. The presence of traces of impurities in the liquid metal often greatly affects the surface tension and the presence of corrosion films on the pipework modifies the wetting characteristics. These factors play an important part in the overall heat transfer characteristics. The surface tension of liquid potassium is, however, remarkably low; it is about the same as water.

Viscosity

Viscosities are comparable with water, but at high temperatures sodium and potassium are considerably more fluid.

Thermal Conductivity and Electrical Resistivity

The reciprocal relationship between thermal and electrical conductivities, characterized by the Wiedemann-Franz Law (which states that the product of thermal conductivity and electrical resistivity divided by the absolute temperature is constant for metals), holds well for liquid sodium-potassium and its alloys over a wide temperature range. The thermal and electrical conductivities of the 78K-22Na alloy are substantially lower than the corresponding values for the pure metals.

COMPATIBILITY

The compatibility of various materials with liquid metals will be discussed under the individual metals. Particular emphasis is given to the behaviour of structural materials used for pipework and canning materials, since the corrosion and mass transfer which take place have posed considerable problems.

Mercury

Mercury, as a large-scale heat transfer medium, has been in use since 1922 for reheat cycles in steam/electric power systems, and in this connection Nerad[25] and co-workers investigated the corrosion of steels in liquid mercury.

Although the solubility of iron in mercury is only about 0.4 ppm at 500°C (the highest temperature of the mercury boiler), it was found that over long periods of operation the cooler parts of the circuit became plugged with a crystalline deposit of iron. This resulted from iron dissolving at the higher temperature and subsequently precipitating from a supersaturated solution at the lower temperature. A schematic drawing (Fig. 2) shows the probable stages in this corrosion-mass transfer phenomenon which applies generally to liquid metal behaviour. For the particular case of iron in mercury, the slow and therefore the controlling step is the diffusion of iron in mercury. Since the diffusion path in this stagnant boundary layer is governed by the velocity of the liquid metal, the corrosion is greatly enhanced by high flow rates.

Nerad carried out his early experiments in thermal convection loops or "harps" (Fig. 3) which can only give maximum flow rates of a few feet per second. Whilst these harps have been widely used in recent liquid metal studies, the need to investigate the effect of higher velocities has led to the use of pumped loops (Fig. 4).

It was found by Nerad that small additions, as low as 10 ppm, particularly of titanium and zirconium, to the mercury successfully inhibited this corrosion. The mechanism of this inhibition has been recently investigated and seems to be due to a very thin film of Ti (C, N) on the

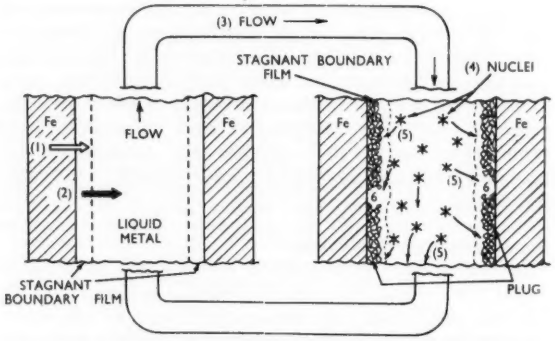


Fig. 2.—Corrosion by mass transfer in liquid metal circuit.
Hot leg: 1, Solution; 2, Diffusion; 3, Transport of dissolved metal.
Cold leg: 4, Nucleation; 5, Transport of crystallites; 6, Crystal growth and sintering (plug formation) (20).

steel, probably formed from carbon and nitrogen present in the steel reacting with the adsorbed titanium film. Low alloy steels containing chromium and molybdenum were also found to be more resistant than plain carbon steels.

Primary mercury cooling was used for the small fast reactor at Los Alamos[8] which operated from 1949-52, and employed plutonium fuel in mild steel cans.

A breeder blanket surrounding the core uses liquid bismuth containing a slurry of Th_3Bi_5 particles in which Th^{232} is converted to U^{233} by capture of excess neutrons escaping from the core. Corrosion problems are associated with pipework, graphite and the behaviour of the breeder blanket. Solutions to these problems are essential if this reactor concept is to be exploited.

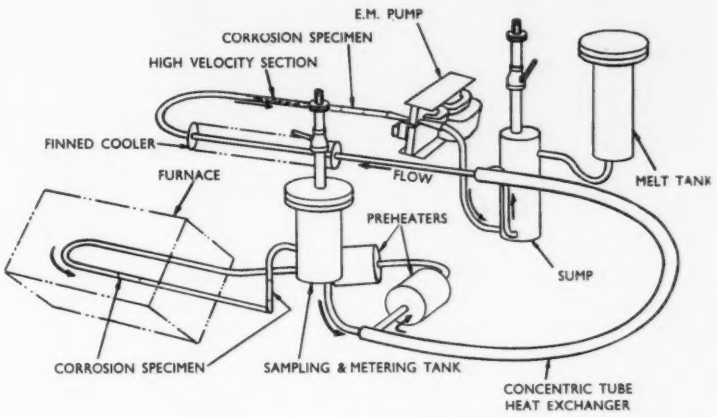
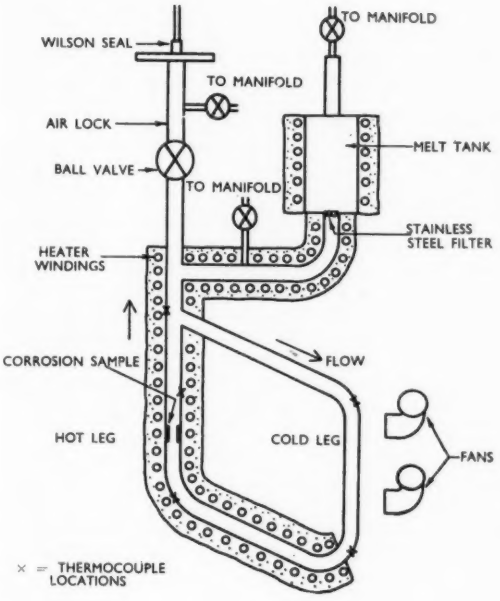


Fig. 4.—(Right) Dynamic corrosion loop (22).

Fig. 3.—(Below) Thermal convection loop or harp (21).



Bismuth

The corrosion of structural materials in molten bismuth is analogous to that in mercury. However, because of its relatively low cross-section for thermal neutrons, bismuth has been an almost invariable choice for a homogeneous liquid metal reactor, which further complicates the corrosion problem. The solubility of uranium in bismuth (Fig. 5) is not large (0.5% at 500°C) but is adequate for the liquid metal to contain sufficient enriched fuel for heat generation. One design proposed by Williams and Miles[17] employs 0.1% U^{233} in molten bismuth which is pumped around a circuit and through a graphite moderator. The heat generated by fission in the graphite core is transferred from the primary circuit to liquid sodium and thence to boiling water. The hot sodium provides both superheat and reheat for the turbine cycle.

Behaviour of Graphite in Bi-U

Because of the stability of uranium carbides the slow removal of uranium from the bismuth solution by graphite can take place. The formation of UC has been demonstrated by reaction at 1,000°C in a lead-bismuth alloy containing uranium. This effect could be successfully inhibited by zirconium, which forms a more stable carbide than uranium.

The radiographs (Fig. 6) show this clearly. The radiation haloes are outlined at the crucible wall and around the graphite inserts when zirconium is absent; the addition of 0.3% Zr eliminates these completely.

Corrosion of Steels in Bi-U

Most constructional metals are appreciably soluble in molten bismuth but iron and low alloy steels, notably 2.25% Cr, 1% Mo and 5% Cr, 1.5% Si, have reasonable corrosion resistance. On the other hand, austenitic stainless steels of high nickel content show poor resistance to attack, mainly as a result of the high nickel solubility in bismuth. A further complication arises with these nickel steels when used with Bi-U solutions, since the uranium solubility in bismuth is reduced and the intermetallic compounds UNi_2 and UNi_5 may be precipitated. The results of extensive work on bismuth carried out at Brookhaven (U.S.A.) have been reported, e.g., Weeks[5] and Gurinsky.[19]

Even with the low alloy steels previously mentioned, corrosion and mass transfer, with ultimate plugging of the cold leg after a few hundred hours, took place in loops operating at 500°-600°C with a temperature gradient of only 40°C.

By analogy with mercury, Ti, Zr and Mg additions were examined. Zirconium was shown to be an effective inhibitor and in similar loops containing 250 ppm Zr in the bismuth no sign of plugging occurred in loops of 2.25% Cr, 1% Mo and 5% Cr, 1.5% Si, after circulating the molten metal for 13,000 and 19,000 hours respectively.

Sodium and NaK

Unlike bismuth, pure sodium and NaK do not appreciably dissolve the common metals of construction. Nevertheless, serious corrosion can take place by a different

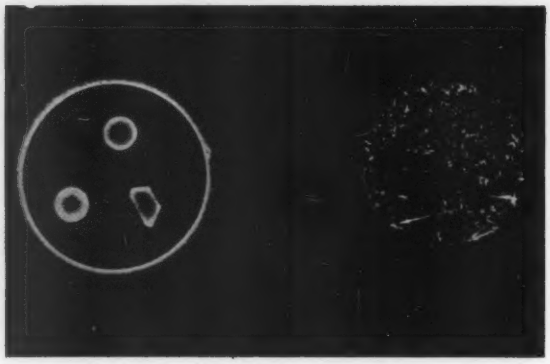


Fig. 6.—Autoradiographs of cross-sections of graphite crucibles after being in contact with Bi-Pb liquid eutectic containing uranium for 100 hours at 1,000°C (7).

mechanism in which dissolved oxygen in the liquid metal plays a vital rôle. As will be seen, the control, elimination and analysis of oxygen combine to limit severely the obvious advantages of these liquid metals, although a large measure of success has been achieved.

Solubility of Oxygen in Sodium

The solubility of oxygen (or sodium oxide) in sodium is shown in Fig. 7, and the curve can be expressed by the equation:

$$\text{Log (wt.\% oxygen)} = -1816/T + 1.266$$

where T is the temperature in °K. The solubility varies from a few ppm at the m.p. to several hundred ppm at higher temperatures. This large temperature coefficient of solubility allows oxygen dissolved at higher temperature to be removed simply by cooling the sodium to an appropriate low temperature at which point excess sodium oxide precipitates.

In practical sodium circuits the circulating sodium is by-passed through a large tank (referred to as the cold trap) containing steel wool and maintained at a low constant temperature, e.g., 120°-150°C. The residence time is relatively long and with a good design the oxygen content of the sodium leaving the cold trap will be close to the theoretical solubility. General experience is that oxygen levels of about 20 ppm are readily achieved.

Lower oxygen levels which are essential for limiting corrosion with certain materials are obtained by the use of "getters." These are metals having a high affinity for oxygen, e.g., titanium, zirconium, magnesium, which can react with dissolved oxygen in the sodium to form an insoluble oxide.

The oxygen content of sodium (and NaK) can be determined by a number of techniques, e.g., amalgamation of the sodium with mercury, followed by separation of the oxide, which is insoluble; a modification of the Wurtz reaction, in which the alkali metal is reacted with butyl bromide leaving the sodium oxide unaffected; a distillation method in which the alkali metal is volatilized *in vacuo* leaving a sodium oxide residue. In all methods the sodium oxide is determined by a standard analytical procedure, usually by a flame spectrophotometer.

The determination and control of these low oxygen levels in large dynamic liquid metal circuits are difficult, particularly in active reactor circuits, where sampling and analysis must be done by remote handling. Physical methods, not requiring sampling and analysis, have been considered. The simplest device is the so-called "plugging meter." This consists of an orifice plate with small holes which is placed in series with a heat exchanger and flow meter in a by-pass circuit. The by-pass stream is independently cooled until a definite restricted flow occurs, which then corresponds to oxygen saturation at the temperature of the cooled by-pass. It is, however, a relatively crude method and for levels below about 20 ppm, more sensitive methods are essential.

Ferrous Materials

Undoubtedly the most valuable material for use in liquid sodium and NaK is austenitic stainless steel, which has been used satisfactorily for long periods up to 600°C and may well be used at higher temperatures. It is not particularly sensitive to oxygen and, in cold trapped sodium, e.g., <50 ppm oxygen, there is no significant attack. At higher concentrations of oxygen, particularly near saturation, intergranular cracking has been observed. Furthermore, accidental contamination of sodium with carbonaceous materials can lead to grain boundary carburization, but both these troubles can be avoided in practice. Ferritic steels are rather less satisfactory than the austenitic in that they are more sensitive to oxygen contamination in the liquid metal.

Low alloy steels are attacked by oxygen containing sodium, and two serious effects have been observed. Surface decarburization occurs at 100 ppm oxygen and 500°C, with the carbon presumably eliminated as CO by reaction with dissolved oxygen. At similar oxygen contents, corrosion of the iron takes place with the formation of a double oxide of sodium and iron, identified by Horsley[9] as $2Na_2O\ FeO$; the mechanism of its formation is obscure.

Non-ferrous Materials

Titanium, zirconium, chromium, vanadium, niobium, tantalum, molybdenum and tungsten have considerable actual and potential uses in liquid sodium, but their satisfactory performance depends more critically on oxygen level than is the case with stainless steel. Many of these metals corrode appreciably in cold-trapped circuits of 20-30 ppm oxygen, and it is essential to reduce the oxygen level by hot trapping with suitable getters. Zirconium foil or swarf of large surface area has been proposed for use as hot-trap material, both here and in the U.S.A., whilst the addition of 100-200 ppm of magnesium to the liquid metal can reduce the oxygen level to only a few ppm.

The mechanism of corrosion of these metals is complicated and not yet fully understood. It seems likely that the initial corrosion product is a simple oxide which is formed by the metal extracting oxygen from the sodium. Subsequently this oxide can form an oxy-salt, e.g., sodium tantalate or niobate, which cracks and spalls off continuously. Thermodynamic considerations show that the oxides and oxy-salts of these metals are generally more stable than sodium oxide, i.e. oxide-saturated sodium. However, dilute oxygen solutions have a corresponding lower thermodynamic activity and it can be shown that at low oxygen levels (achieved by hot trapping) no corrosion is possible. Dynamic corrosion studies relating to some of these metals have been carried out in the laboratories of the Industrial Group of the U.K.A.E.A. and reported by Davis and Draycott[10] at Geneva. Zirconium can be used in highly deoxidized sodium, but both titanium and beryllium form non-adherent oxide films even at low oxygen levels.

Uranium is compatible with static sodium up to 700°-800°C but is severely corroded in a flowing system in the presence of oxygen.

Copper, magnesium, aluminium and alloys based on them are not suitable for long-term use in liquid sodium and NaK.

(*Continued on page* 63)

Nuclear Engineering
DATA SHEET
No. 13. Liquid Metals

TABLE A2. Vapour Pressure Equations

Liquid metal	log p (mm Hg)
Hg	$-3305/T-0.795 \log T+10.355$
Bi	$-10,060/T-1.325 \log T+12.70$
Na	$-5220/T+7.402$
K	$-4207/T+6.977$

(Temperature T) expressed in °K)

TABLE AI
Comparison of Properties of Liquid Metals

Property	Mercury	Bismuth	Sodium	Potassium	78%K—22%Na	Reference No
Atomic weight	200.6	209.0	22.99	39.10	33.9 (calc)	
Melting point (°C)	—39	271	98	64	—11	1
Latent heat of fusion (cal/g)	2.8	12.0	27	14.6	—	1
Boiling point (°C)	357	1477	881	757	784	1, 2
Latent heat of vaporization (cal/g)	69.7	204.3	1005	496	—	1
Vapour pressure	Table A2	Table A2	Table A2	Table A2	—	2, 16
Density	Fig. 8	Fig. 8	Fig. 8	Fig. 8	Fig. 8	1, 2
Heat capacity	Fig. 9	Fig. 9	Fig. 9	Fig. 9	Fig. 9	1, 2
Viscosity	Fig. 10	Fig. 10	Fig. 10	Fig. 10	Fig. 10	1, 2
Thermal conductivity	Fig. 11	Fig. 11	Fig. 11	Fig. 11	Fig. 13	1, 2
Electrical resistivity	Fig. 12	Fig. 12	Fig. 12	Fig. 12	Fig. 13	1, 2
Surface tension (dynes/cm)	394 (354°C)	363 (500°C)	161 (400°C)	86 (100°–150°C)	110 (250°C)	1
Volume change on fusion (% of solid volume)	3.6	—3.3	2.5	2.4	2.5	1, 2
Nuclear cross-section for thermal neutrons:						
Microscopic absorption (barns)	360	0.032	0.515	1.97	—	15
Macroscopic absorption (cm^{-1})	14.7	0.001	0.013	0.026		
Heat of formation of oxide $\Delta H°_{298}$ (kcal)	—22 (HgO)	—46 ($\frac{1}{3}$ Bi_2O_3)	—100 (Na_2O)	—86 (K_2O)	—	16

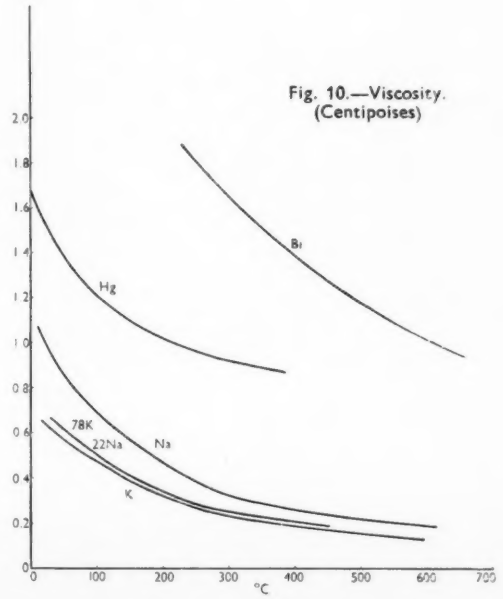


Fig. 10.—Viscosity. (Centipoises)

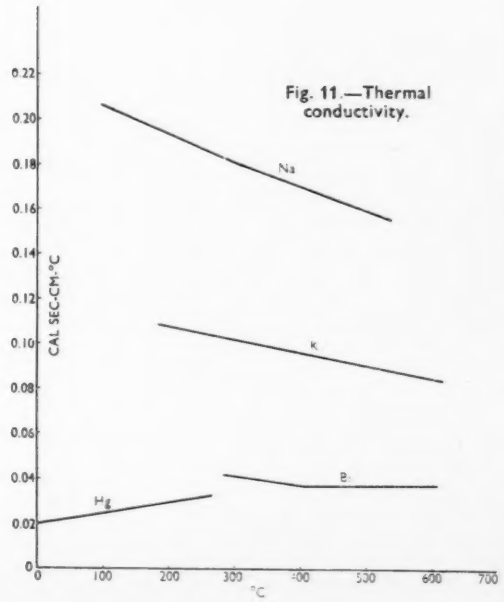


Fig. 11.—Thermal conductivity.

Vapour Pressure Equations

log p (mm Hg)
−3305/T−0.795 log T+10.355
−10,060/T−1.325 log T+12.70
−5220/T+7.402
−4207/T+6.977

ature T) expressed in °K)

ssium	78%K—22%Na	Reference No.
.10	33.9 (calc)	
64	—11	1
4.6	—	1
57	784	1, 2
96	—	1
e A2	—	2, 16
g. 8	Fig. 8	1, 2
g. 9	Fig. 9	1, 2
. 10	Fig. 10	1, 2
. 11	Fig. 13	1, 2
. 12	Fig. 13	1, 2
°–150°C)	110 (250°C)	1
.4	2.5	1, 2
97		
026	—	15
(K2O)	—	16

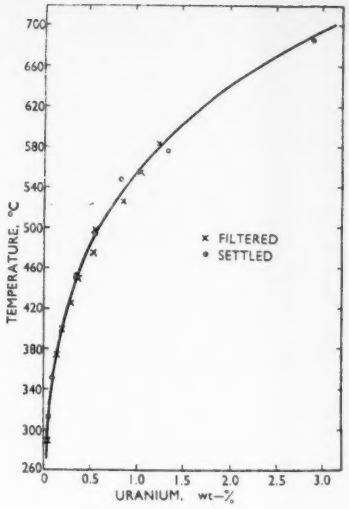


Fig. 7.—(Righ
sodium oxide
sodium as a fu
peratu

Fig. 5.—(Left)
uranium in liqu

Fig. 8.—Density.

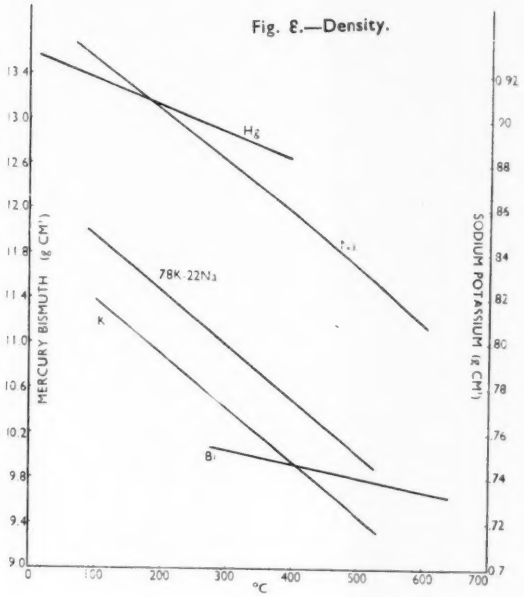


Fig. 11.—Thermal conductivity.

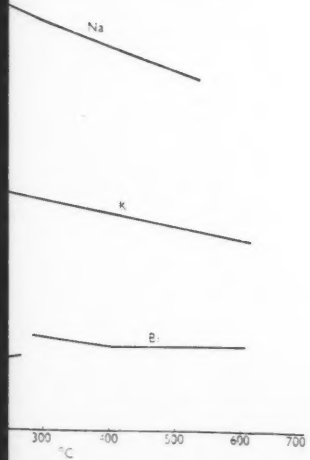
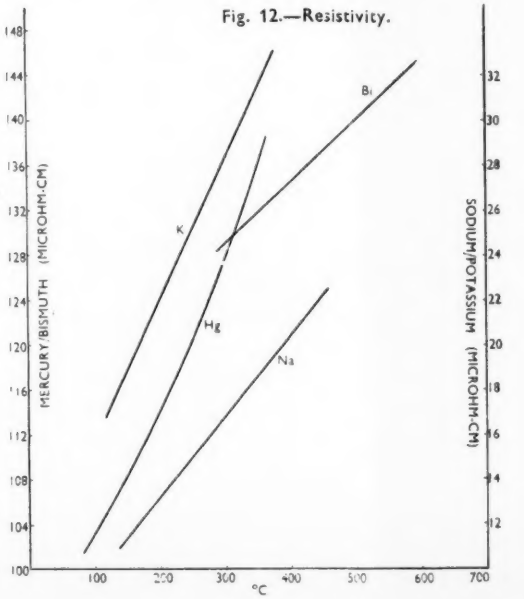
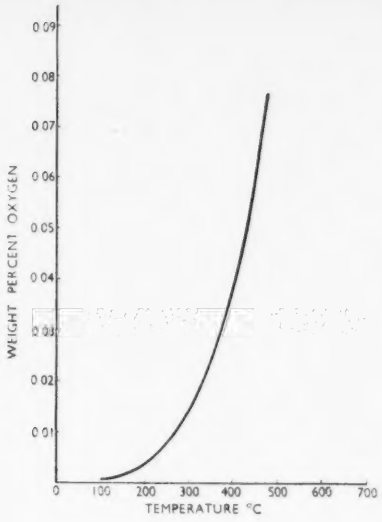


Fig. 12.—Resistivity.



ig. 7.—(Right) Solubility of odium oxide (as oxygen) in odium as a function of temperature (23).



ig. 5.—(Left) Solubility of ranium in liquid bismuth (6).

Fig. 9.—Heat capacity.

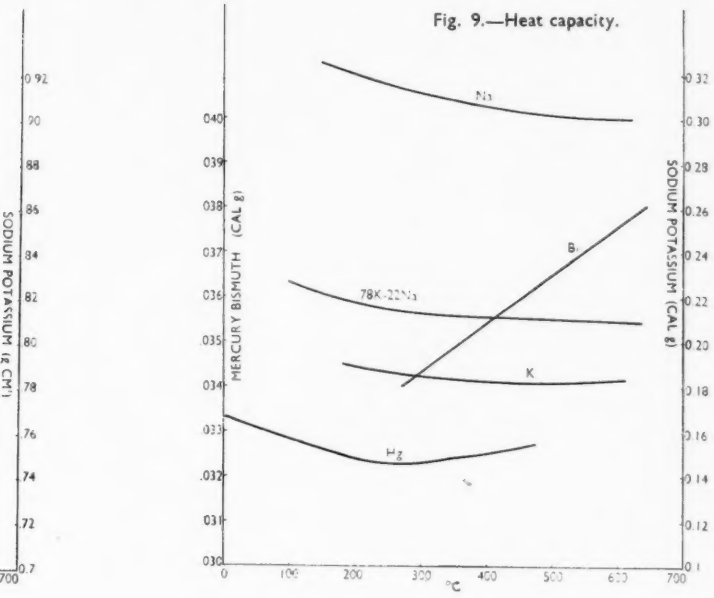
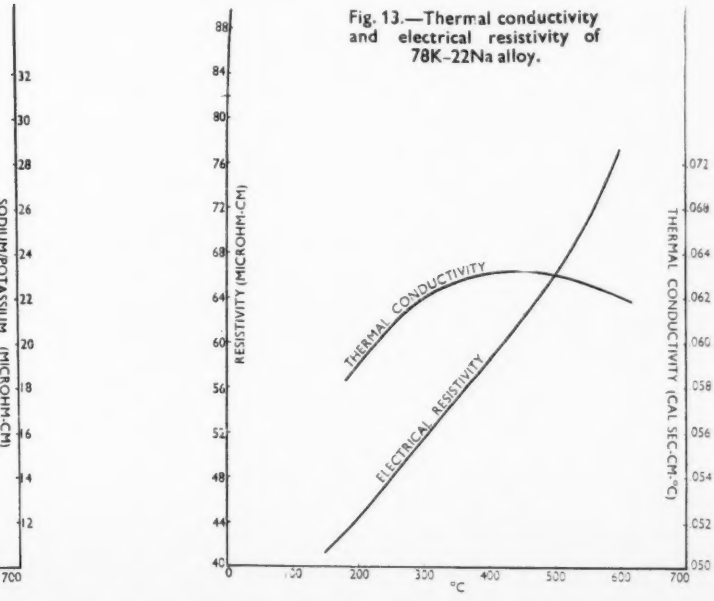


Fig. 13.—Thermal conductivity and electrical resistivity of 78K-22Na alloy.



Ceramics and Graphite

Ceramic materials may be affected chemically either by sodium (or dissolved sodium oxide) or physically by absorption of liquid metal in the pores or grain boundaries. Silica and silicates are readily attacked chemically. The behaviour of more stable oxides depends on their physical state. Single crystals are scarcely affected, e.g., sapphire (Al_2O_3) and periclase (MgO), whilst highly fired dense bodies, preferably self-bonded, of thoria, zirconia and beryllia have possible application in liquid sodium up to 500°C.

Graphite of all varieties is attacked by sodium. With appreciable oxygen dissolved in the liquid metal, carbon is probably removed as CO. Complete penetration of the pores also occurs which cracks the graphite and may eventually lead to complete disintegration.

Whilst it has been difficult to establish direct reaction between graphite and sodium to form a lamellar compound analogous to the potassium compound, the traces of potassium in sodium are an inevitable source of trouble. It is possible, though not yet explored, that high-density graphite of zero porosity would be satisfactory in pure sodium of very low oxygen content.

REACTOR APPLICATIONS

The broad choice of materials for any particular liquid metal reactor design can now be made rationally, although extensive prototype testing is necessary under both active and inactive conditions. Apart from the general effects of radiation on the pattern of corrosion and material stability, there is always the likelihood that corrosion with mass transfer can lead to the deposition of relatively high radioactivity in parts of the circuit remote from the core, e.g., in heat exchangers and pumps. This makes maintenance difficult, and emphasizes the need for simple circuits. If moving parts are used in liquid metals, there is the further danger of self-bonding taking place between metal surfaces in contact, because of solution and diffusion in the liquid metal.

The present proposals for large-scale liquid metal reactors reflect the view that sodium cooling is the most promising. In the U.S.A., a sodium-cooled graphite-moderated reactor of 20 MW (thermal) has been operating for some time.[11] The graphite is canned in zirconium and a hot trap, using zirconium foil of large surface area, is used to achieve low oxygen levels in the sodium. In the U.K., the Dounreay Fast Reactor will come into operation very shortly. This is rated at 60 MW (thermal) and employs highly enriched uranium contained in a composite can of niobium and vanadium. Both Na and NaK coolants will be used and these will be continuously deoxidized with zirconium.

Koch[12] has recently reviewed the U.S. fast reactor programme. Two large-scale sodium-cooled reactors are due to come into operation in 1959/60. These are the EBR-II, of similar rating to Dounreay, and the Enrico Fermi Fast Breeder Reactor (EFFBR), which has a thermal rating of 300 MW. Both reactors will use solid-fuel elements based on uranium and plutonium "fissium"* alloys. These are being developed with the emphasis on remote processing and fabrication. The retention of several per cent of fission products, notably molybdenum and ruthenium, which results from pyrometallurgical processing, confers remarkable irradiation stability on the fuel.

Apart from their main use as coolants, liquid metals have other reactor applications. Liquid plutonium and its alloys are now being considered as advanced fuels which are completely canned and separated from the coolant. In fuel processing many liquid metals, e.g., zinc, aluminium, have been proposed for high-temperature fuel treatment to remove fission products.[13]

* Fissium is the equilibrium mixture of fission products that remain in the fuel after many process cycles.

SAFETY PRECAUTIONS

Mercury vapour is highly poisonous. The maximum safe limit for continuous exposure is considered to be 0.1 mg/m³, while the normal saturation vapour pressure of mercury at room temperature corresponds to a theoretical value of 20 mg/m³. The handling of hot mercury, therefore, requires considerable care and constant monitoring of the working space around equipment carrying the liquid metal is essential.

Bismuth does not appear to be dangerous, although, in common with other metal vapours, prolonged exposure to hot bismuth vapour may cause irritation and discomfort.

Neither bismuth nor mercury constitute a significant fire risk when exposed to air.

Sodium and potassium are not poisonous but their extreme reactivity with air, water and other oxidizing gases means a fire and explosion hazard. The liquid metals should be handled under oxygen-free dry argon or nitrogen and all equipment should be thoroughly dry. Personnel should be equipped with gloves and goggles and, where large quantities of sodium or potassium are involved, complete protective clothing with respirators is recommended.

Sodium fires can be extinguished with solid materials, e.g. anhydrous sodium carbonate or salt. Carbon tetrachloride or CO_2 extinguishers must not be used.

Sodium and potassium residues in equipment may be cleared with low-pressure steam, but caustic residues may be difficult to remove completely. Both sodium and potassium metals can be dissolved, without residue, by anhydrous liquid ammonia.

Liquid sodium has been successfully handled for many years on a large scale[14] and with reasonable precautions there is no exceptional hazard.

Acknowledgments

Thanks are due to Sir Leonard Owen, Managing Director of the Industrial Group, U.K.A.E.A., and Dr. H. Kronberger, Director of Research and Development, for permission to publish this article.

Translations see page 58

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THE NUCLEAR FIELD IN NORWAY

A brief survey of the general pattern of development and some of the organizations

NORWAY, unlike Great Britain, has no immediate and urgent need for nuclear energy. With hydro power being sold to the domestic consumer at about 0.3d per unit, nuclear generation cannot possibly compete on an economic basis. In addition, Norway is by no means a rich country since the population is small—less than half that of Greater London—and although the land area is large (125,182 sq. miles), it is in the form of a long and narrow strip (land frontier 1,591 miles, coast line 1,647 miles, not including bays and fjords), much of the country being comparatively inaccessible and not suitable for agriculture.

Nevertheless, the Norwegians have taken an active participation in nuclear matters for a long time although their work has not always been widely publicized.

At first sight, the pattern of nuclear work in Norway appears a little complicated, and it is felt that a brief review of the various organizations existing, and their scope and function, may prove of interest.

IFA

The Institutt for Atomenergi, which forms the heart of the Norwegian nuclear energy industry, was founded by decree of the Norwegian Government in 1948. It is an independent foundation, dealing with research and other activities. Finance has been from Government funds, via the Royal Norwegian Council for Scientific and Industrial Research, and from Norsk Hydro, a commercial company with wide interests in the manufacturing and power supply fields, one of its activities being the manufacture of heavy water. The headquarters of the IFA are at Kjeller near Lillestrøm a dozen miles from the capital.

JENER

The Joint Establishment for Nuclear Energy Research is the joint Norwegian-Dutch training centre, established in 1951 by agreement between the IFA and the FOM (Fundamentec Onderzoek der Materie) of the Netherlands. In 1955, the agreement with FOM was replaced by one with RCN (Reactor Centrum Nederland) when that body was created ("Nuclear Energy in Holland," *Nuclear Engineering*, August, 1957, p. 327). JENER also has its headquarters at Kjeller, where it operates the reactor JEEP and the Netherlands-Norwegian Reactor School.

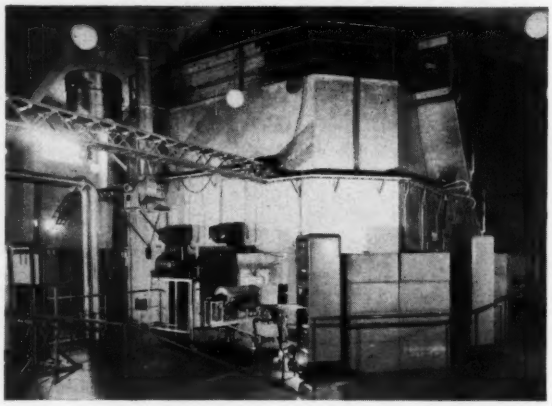
HBWR

The Halden Boiling Water Reactor, a full description of which is to be published shortly, is located at Halden, in south-east Norway, some 80 miles from Oslo. This project was designed by JENER, built by IFA largely from Government funds, with some contribution from Norsk Hydro. The actual construction was carried out by IFA in conjunction with the KMT combine and the Chr. Michelsens Institute, about which more will be said later.

For operation of the reactor, six European countries, in addition to the Euratom countries, are contributing for a period of three years. The O.E.E.C. provides secretarial services.

Kjeller

As previously mentioned, Kjeller is the headquarters of both IFA and JENER. Although by Harwell standards Kjeller is small, it is a thriving establishment which is steadily expanding. The main features of interest in addition to the normal laboratories and drawing offices are the new hot laboratories, the reactor JEEP, and the Netherlands-Norwegian Reactor School.



JEEP from the north-west.

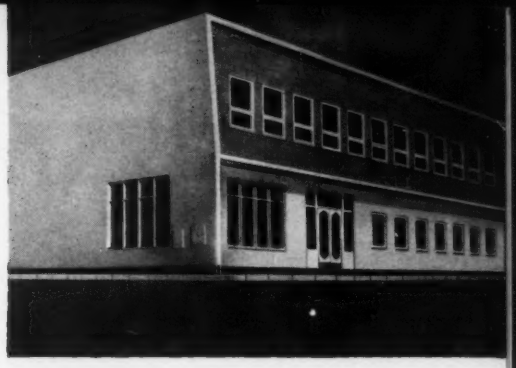
The new hot laboratories are intended for experimental processing of irradiated fuel elements from JEEP and HBWR when this goes into operation. The plant, on which development has been under way for some years is practically complete, liquid-liquid extraction with pulsed columns being used.

JEEP, one of the most senior reactors in Europe (criticality having been achieved in July '51) is a small (0.5 MW) natural uranium heavy water reactor of outstanding simplicity of design, giving 420 MWd operation up to Dec., 1958, according to the latest figures which are available. Isotope shipments from Kjeller amounted to some 3,608, as well as 1,412 irradiations made for use inside the establishment, up to the same date.

The Reactor School was formally opened in April, 1958. The new building, which was erected with the aid of an extra grant from the Government of the Netherlands, contains lecture and demonstration rooms, and study-and-group-discussion rooms.

The "standard" course lasts for nine weeks, and is intended to give a balanced review of the field of nuclear engineering to graduate engineers, and accommodation can be provided for 30 students on each course. Other courses are available for senior technical executives and science teachers. A simulator is available, and other experimental work can be carried out on JEEP.

Kjeller has, at the moment, some 250 persons working there. The majority are, of course, Dutch and Norwegian, but many other nationalities are represented.



The Reactor School.

CMI

The full title of this organization is "The Chr. Michelsens Institute for Science and Intellectual Freedom," and it is located in Bergen. Michelsen, the founder, was a ship-owner and statesman in the early part of the century. It carries on a considerable programme of pure scientific research as well as work in the arts and humanities; it also undertakes research projects on a commercial basis, as well as manufacturing where ultra high-class workmanship is required, e.g., scientific instruments, of which it has a considerable output. Amongst its achievements can be numbered the construction of Oslo's solar observatory, and JEEP. CMI was also responsible for the control mechanisms of the Halden reactor.

KMT

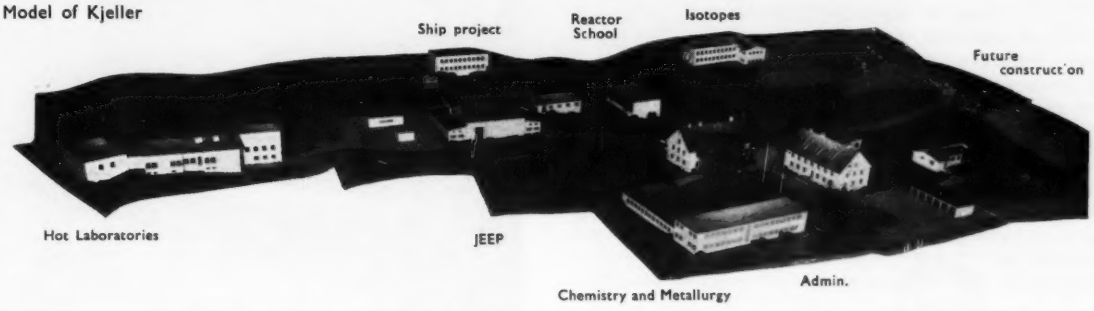
The KMT, or Kværner-Myrens-Thunes association, represents three heavy engineering companies, all of which supplied some considerable amount of the Halden reactor.

Kværner Brug specializes in hydro-electric turbine and large lathes for putting the fine mirror finish required on calender bowls for paper-making plant of the largest size. They employ about 500 men—rather more than Kværner Brug, who have larger shops and heavier machinery. All three members of the KMT group are members of Noratom.

Noratom

Noratom was founded in June, 1957, and consists of a group of companies desirous of entering the nuclear field. Unlike a British consortium, the group is larger, and made up of smaller units, with a greater diversity of interests. A list of its members is given below.

Model of Kjeller



machinery and is capable of handling quite heavy material, producing the pressure vessel and primary system for the Halden reactor. Myrens Værksted A/S specializes in heavy machinery. Thunes Mek Værksted A/S manufacture boilers, railway locomotives and paper-making machinery, and are the Norwegian licensees of Babcock and Wilcox, Ltd. They are equipped with bending rolls that will handle plate up to about 1½ in., for pressure vessel manufacture

The Ship Project

Rederiatom is a group of shipowners, who have jointly subscribed 1½ million kroner (approximately £75,000) for a preliminary study of a nuclear-propelled ship to be undertaken by IFA. This is another project under way at Kjeller.

MEMBERS OF A/S NORATOM

ALUMINIUM PRODUCERS
A/S Nordisk Aluminiumindustri, Lokkeveien 9, Oslo.
A/S Ardal og Sunndal Verk, Nedre Vollgate 4, Oslo.

ARSENALS
Kongsberg Vapenfabrik, Kongsberg.
Raufoss Ammunisjonsfabrikker, Raufoss.

BANKS
Bergens Privatbank, Kirkegate 23, Oslo.
Christiania Bank og Kreditkasse, Stortorvet 7, Oslo.
Den Norske Creditbank, Kirkegaten 21, Oslo.

CEMENT
A/S Christiania Portland Cementfabrik, Fr. Nansens plass 6, Oslo.

COPPER MINING
Orkla Grube-Aktiebolag, Lokken Verk, Orkla.

CIVIL AIRLINE
Braathens S.A.F.E., Fr. Nansens plass 7, Oslo.

ELECTRICAL EQUIPMENT
A/S National Industri, Braker oya, Drammen.
Standard Telefon—og Kabelfabrik A/S, Ulvenveien, Okern, Oslo.
Sverre Munck, Mollendalsbk 1, Bergen.

ELECTRO CHEMICAL
Norsk Hydro-Elektrisk Kvaelstofaktieselskab, Solligate 7, Oslo.

ELECTRO-METALLURGICAL EQUIPMENT
Elektrokjemisk A/S, Radhusgate 23, Oslo.

ENGINEERING CONTRACTORS
A/S Hoyer-Ellefsen, Tollbudgate 30, Oslo.
Ingenior F. Selmer A/S, Hausmannsgate 34, Oslo.

INSURANCE
Norsk Forsikringsselskap A/S (Aeolus), O. Slottsgate 21, Oslo.
Storebrand, Kirkegate 24, Oslo.

MACHINERY
Christiania Spigerverk (Iron and steel works and foundry), Nydalen, Vestre Aker.
Jorgen S. Lien (office machines), Mollendalsvei 2-4, Bergen.
Kvaerner Brug (hydro-electric turbines), Enebakkveien 65, Oslo.
A/S Myrens Verksted (industrial machinery), Bentsebrugate 20, Oslo.
A/S Strommens Verksted (ship's propellers, bus-body builders, etc.), Strommen St.
A/S Thunes Mek. Verksted (locomotive manufacturers and direct suppliers of heavy metal components to Halden reactor), P.B.225, Oslo.

PAPER AND PULP
A/S Borregaard, Sarpsborg.
Honefoss Fabrikker, Honefoss.
Mathiesen-Eidsvold Verk., Bon.
Saugsbrugsföreningen, Halden.
A/S Union Co., Nedre Vollgate 4, Oslo.

PRIVATE ELECTRICITY UNDERTAKINGS
A/S Hafslung, Slemdalsveien 37, Fron, Oslo.

SHIPBUILDING
Akers Mek-Verksted, Dokkeveien 1, Oslo.
A/S Bergens Mekaniske Verksteder, Bergen.
A/S Frederikstad Mek. Verksted, Fredrikstad.
Marinens Hovedverft, Horten
A/S Rosenberg Mek. Verksted, Kronprinsensgate 5, Oslo.

SHIPPING
Sig. Bergesen d.y. and Co., Drammensveien 106, Oslo.
Den Norske Amerikalinje A/S, Jernbanetorget 2, Oslo.
Leif Hoegh and Co., A/S, Parkveien 55, Oslo.
Fred Olsen and Co., Fred Olsensgate 2, Oslo.
Wilh. Wilhelmsen, Tollbodgate 20, Oslo.

SOAP
A/S Lilleborg Fabriker, Sandakerveien 54, Oslo.

WHALING
A/S Thor Dahl, Sandefjord.
Anders Jahre and Co., Sandefjord.

WHALE-OIL REFINERIES
De No Fa A/S, Prinsensgate 2, Oslo.

MULTI-UNIT STEAM GENERATORS

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(*The Superheater Co., Ltd.*)

This article discusses the case for the use of a large number of comparatively small heat exchangers, as in the French reactor EDF1, in contrast to established British practice.

AT Calder Hall there are four steam generators per reactor, each about 80 ft high and 17 ft in diameter, each forming part of a self-contained gas loop. In the present round of nuclear stations, the same general arrangement is retained, though the number of loops per reactor has been increased from four to six and, in one case, to eight—the object being to reduce the fraction of the plant thrown out of action if a fault develops in any one loop.

These large-diameter steam generators all have the same general characteristics. There are two steam circuits, H.P. and L.P., each having economizer, evaporator and superheater banks. The elements in each bank are in the form of loops or horizontal tubes in cross-flow, with or without extended surface, connected by close-return bends. Forced circulation is used, and the steam drums and headers are placed outside the towers, connections from each individual element passing through the shell.

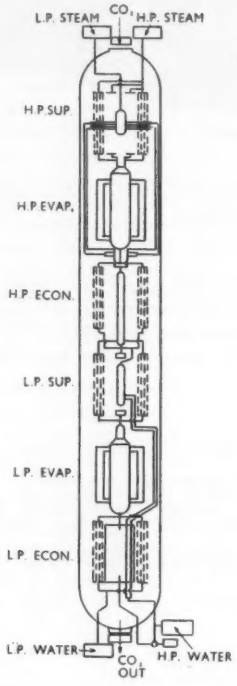


Fig. 1.—Diagram showing general arrangement of circuits in EDF1 heat exchanger.

For erection and maintenance reasons, access space is allowed between each bank of elements. These dead spaces considerably increase the height and, therefore, the cost, of the shell.

The shells are fabricated from very heavy plate and weigh some hundreds of tons, so that they must be built at site, unless transport by sea is possible. The cost per ton is inevitably high.

The elements must be installed in the shells after erection, an operation involving many thousands of site welds. Site work is always more expensive than factory work; furthermore, quality control, which must be very stringent in work of this type, is harder to achieve.

A further problem arises over the requirement that all surfaces swept by the gas stream must be "clean." The shells have to be shot-blasted internally after erection, and the elements pickled or shot-blasted in the factory and then transported to site in special air-tight cases; or, alternatively, slushed after cleaning and then degreased at site, when required for erection.

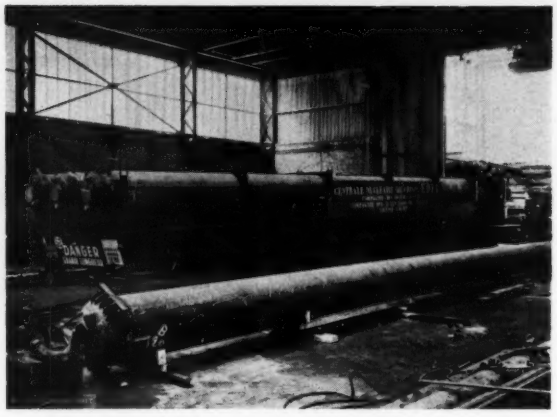


Fig. 2.—Three EDF1 half-towers, complete with elements, leaving the works of the Compagnie des Surchauffeurs.

Alternative Designs

These difficulties have directed attention to alternative steam-generator designs. There are two possible approaches to the problem: to increase the number of loops per reactor, or, in each loop, to replace one big tower by a number of small ones. In both cases, the objective is a heat exchanger which can be prefabricated complete with its elements in the factory under "clean" conditions, and then transported to site for erection.

For road transport, the limit is 80 to 100 tons, i.e., 4 ft to 5 ft diameter if a tower is shipped in a single length, or around 6 ft 6 in. diameter if in two lengths. For a 500 MW(E) station, some 36 towers of the larger diameter might be needed per reactor, and this number of loops would be impracticable.

The French Solution

There remains the possibility of grouping a number of small towers in each loop. French engineers have tackled the problem with characteristic "élan," and for EDF1 (75 MWE) are using 120 steam-raising units or towers, each about 90 ft high, 2 ft diameter and 18 tons in weight, including elements. The towers are shipped to site in two halves (Fig. 1). The top half contains the H.P. superheater, the H.P. evaporator and H.P. economizer, and the bottom half the L.P. superheater, L.P. evaporator and a

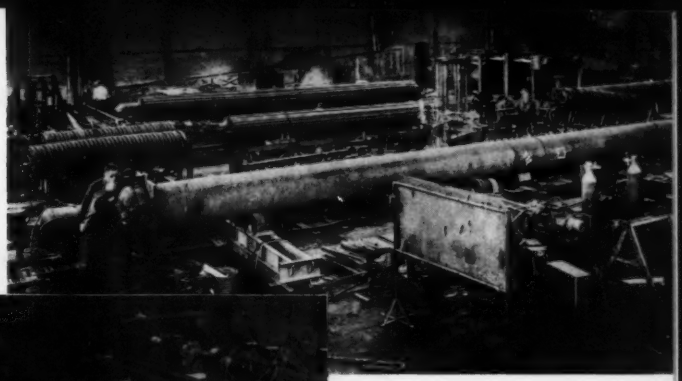
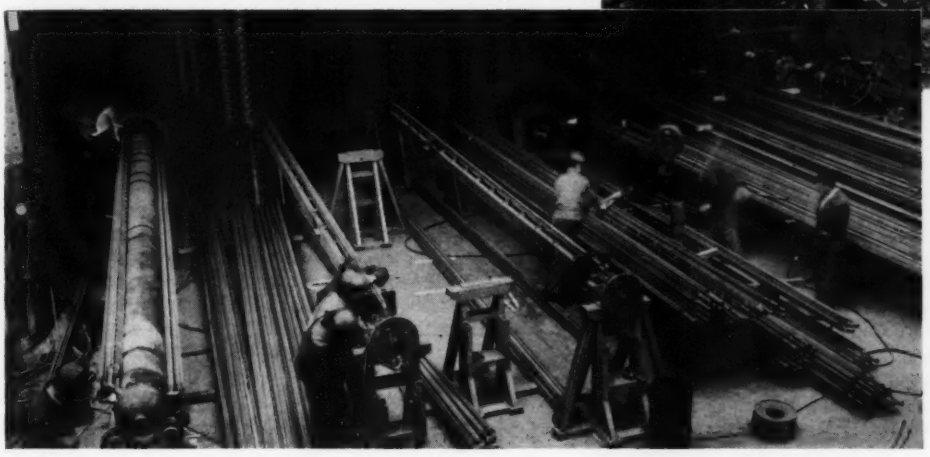


Fig. 3.—(Right) Shell (in foreground) ready to receive elements. In the background are a superheater (helical coil) assembly and an evaporator (finned tubes).

(Courtesy Cie des Surchauffeurs)



(Courtesy Cie des Surchauffeurs)

Fig. 4.—(Left) Evaporator assembly. On left, radial sub-headers, each carrying two finned tubes, are being welded to nipples extruded from the internal drum.

mixed economizer. All connections, gas, steam and water, are taken through the ends of the shell, so that the barrel is left clear of projections.

The superheater and economizer banks each consist of four concentric helical coils. Each helix may have one or more starts so that the number of paths in parallel can be varied according to the duty. The evaporator section consists of a cylindrical drum about 1 ft in diameter and 25 ft long. At the bottom and top of this drum radiate sub-headers and between these, externally finned tubes are welded, running parallel with the axis of the shell (Figs. 1 and 3). The superheater tubes are thus in cross counter-flow and the evaporator tubes in pure counter-flow.

To allow for thermal expansion, the upper bank in each half-tower is hung from the upper shell end-cap; the remaining elements being hung from it by means of rods. Pipe connections between banks are made by means of bold loops.

Pickling of the gas-side surfaces is to be carried out at site after the towers have been erected so that there is no need for factory assembly under " clean " conditions. This is a bold step which, if successful, will certainly save a great deal of trouble and expense. However, even if the method should prove unacceptable, clean assembly of small-diameter towers in the factory remains a relatively simple matter.

Whilst the total shell weight is about the same as if large-diameter towers were used, the cost per ton is very much less since the thickness of plate is under $\frac{1}{2}$ in. and all fabrication is carried out at the works.

The towers are connected, on the gas side, to sub-headers, there being 30 towers (15 per side) to each. These sub-headers connect at each end to the main gas ducts from and to the reactor. The method of support is interesting. Each top gas header, with its associated 30 towers, is hung from a cross-beam, secured to the two gas ducts from the reactor and running on tracks, so that the whole assembly is free to expand or contract with the ductwork (Fig. 6).

Any tower can be removed by simply cutting the gas and water/steam connections at the top and bottom. It is estimated that a tower can be removed and a new one substituted within 24 hours.

Operational Features

This French design has many interesting features. Natural circulation is used in the evaporators so that the cost of pumps, external drums and associated pipework is saved. The water level in the internal drums is controlled from four of the 120 towers which are selected as control towers and provided with level gauges. An electronic controller averages the four levels and sends the necessary

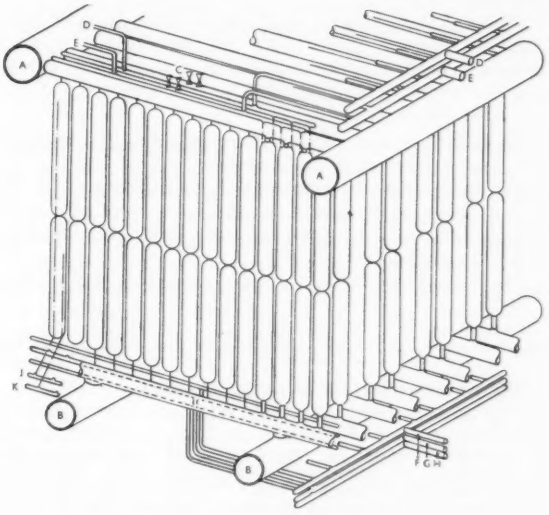


Fig. 5.—General arrangement of heat exchangers in banks.

(A) Hot gas ducts; (B) Cold gas ducts; (C) Safety valves; (D) HP steam out; (E) LP steam out; (F) HP water in; (G) LP water out; (H) LP water in; (J) HP balance tubes; (K) LP balance tubes.

signal to the feed pump. All the evaporator drums are cross-connected by pipes passing through the bottom of the towers to common headers, this pipework system also being used for blow-down.

The water capacity of the evaporator drums is

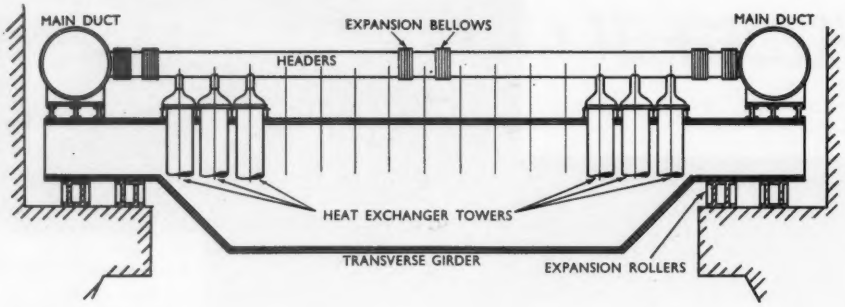


Fig. 6—Method of supporting towers to allow for movement with expansion of main ducts.

considerable. At full steaming rate, the level falls only a few inches a minute if feed-water is cut off. As the drums are 20-25 ft high, they hold enough water for over half-an-hour's steaming.

Rapidity of Prototype Testing

An important advantage of the multi-unit system is that one can build a prototype tower and put it on test before bulk production starts. For example, an EDF1 tower has been on test at St. Denis Power Station since early last summer. The tests have been highly successful and useful. They have shown, generally, that the design is well up to specification. In fact, some of the banks were found to be over-surfaced and worthwhile modifications were possible. Similarly, although the order for the EDF2 steam generators was placed only last autumn, the prototype will be on test this spring. Clearly, the whole tempo of development is stepped up when designs can be checked so quickly.

Optimum Size?

Probably the optimum design lies at some diameter intermediate between Calder Hall and EDF1, and will, of course, depend to some extent on the size of the reactor and the operating conditions. The following are, perhaps, the most important criteria:

(1) The shell cost per ton increases with wall thickness and therefore with diameter.
(2) Fabrication of complete heat exchangers at the works is obviously economical. Here the transportation limit is 80 to 100 tons, max. diameter 6 ft 6 in.
(3) Forced circulation is more expensive than natural circulation, and for the latter the upper limit seems to be in the range 4 ft to 6 ft diameter. At any rate, at about this diameter one probably reaches the limit for the concentric type of element (such as the helix) and for elements consisting of longitudinally-finned tubing. For diameters above this, one must use horizontal, straight tubes in cross-flow, and here the longest element (and therefore the largest diameter) is the cheapest, as requiring the minimum number of welds and return-bends per foot run of tubing.
(4) As the diameter is made smaller, the number of towers per loop must, of course, be increased and the ductwork therefore becomes more complicated and expensive. This, to some extent, offsets the effect of (1), above.
(5) For a 500 MW(E) two-reactor station and operating conditions at current levels, the optimum appears to lie at about 5 ft diameter (10 towers per loop) shipped to site in two halves. In practice, however, lighter towers, say 4 ft diameter (about 16 towers per loop), may provide the cheapest solution since they can be more readily fabricated by quantity-production methods.

The case for small-diameter heat exchangers can be summarized as follows:—

Towers can be fabricated with elements in the factory by quantity-production methods and under controlled and "clean" conditions: they can then be more or less "plugged-in" at site with a minimum of welding. Apart from this, important economies stem from the use of natural circulation, from the avoidance of heavy plate and possibly, also, from pickling at site.

Générateurs de Vapeur à Groupes Multiples

Un grand nombre de petits échangeurs de chaleur, tels qu'employés par l'Electricité de France, semblent posséder certains avantages par rapport à un petit nombre de grands échangeurs de chaleur, tels qu'employés à Calder Hall et dans les centrales britanniques. Outre l'emploi de plaques de coquille plus minces, donnant une plus grande facilité de fabrication, les autres avantages comprennent la possibilité d'un montage en usine et une réduction considérable des opérations de soudure et de nettoyage intérieur sur les lieux. L'auteur est d'avis que la grandeur optimum pourrait se situer entre les deux extrêmes mentionnés, et suggère 10 tours par boucle, ayant chacune environ 1 m. 50 de diamètre, transportée en deux moitiés.

Vielfach-Dampferzeuger

Es scheint, als ob die Verwendung einer grossen Zahl von kleinen Wärme-Austauschern, wie sie von der Electricité de France benutzt werden, gegenüber einer kleinen Anzahl von grossen Wärme-Austauschern, wie sie in Calder Hall und den britischen Werken benutzt werden, gewisse Vorteile hat. Ausser der Verwendung schwächerer Aussenbleche, die leichter herzustellen sind, bringen sie noch weitere Vorteile mit sich, wie z.B. die Möglichkeit der Montage in der Fabrik und beträchtliche Verringerung der Schweissarbeiten und der inneren Reinigungsarbeiten an der Baustelle. Der Autor ist der Meinung, dass das Optimum zwischen den beiden oben erwähnten Extremen liegt, und so schlägt er vor, 10 Türme für jeden Umlauf zu wählen, von denen jeder 5 Fuss (1,5 m) Durchmesser haben sollte, und der dann in zwei Hälften transportiert würde.

Generadores de Vapor de Unidades Múltiples

Un gran número de cambiadores de calor pequeños, como los usados por Electricité de France, parecen tener ciertas ventajas al compararse con un pequeño número de grandes cambiadores de vapor, como los que se usan en Calder Hall y las centrales británicas. Además del empleo de planchas de casco más delgadas, ofreciendo mayor facilidad en la fabricación, las otras ventajas incluyen la posibilidad de montaje en fábrica y una reducción considerable en el trabajo de soldadura y limpieza interna en sitio. El autor considera que el tamaño óptimo puede estar entre los dos extremos mencionados, y sugiere 10 torres por lazo, cada uno de unos 5 pies (1, 5 metros) de diámetro, transportadas en dos mitades.

WIGNER ENERGY STORAGE

Its Relation to Reactor Design

By P. J. GRANT, M.A., Ph.D.
(*Atomic Energy Division, The General Electric Co., Ltd.*)

The phenomenon of Wigner energy storage in graphite is considered in this article. Annealing problems are discussed, together with possibilities of avoiding the necessity for annealing by operating the graphite at higher temperatures.

AS all moderators in the core of a power reactor are subjected to very intense bombardment by neutrons and gamma radiation they inevitably suffer radiation damage. With light and heavy water this takes the form of radiolytic dissociation but with graphite the radiation damage consists of disturbance to the crystal structure which leads to a variety of symptoms loosely classified as " the Wigner Effect."

Effect of Irradiation

Collision of fast neutrons with carbon atoms in the graphite crystals causes these atoms to be knocked out of position and the immediate result is thus a vacancy in the lattice.[1, 2, 3, 4] The displaced atoms are themselves moving fast, and may cause further atoms to be ejected from their regular lattice positions. The production of vacancies together with the single atoms, or groups of atoms lodged in positions between the lattice planes (interstitial atoms) causes a distortion of the crystal lattice, and the macroscopic effects of neutron irradiation are a direct consequence of this.

Clearly a possibility exists for the recombination of interstitial atoms with lattice defects, in other words annealing of the radiation damage. As the varieties of defect, and the distance between vacancies and displaced atoms can vary greatly, the lifetimes of defects against self-annealing at ordinary room temperatures, for example, will vary from small fractions of a second to hundreds of years. Raising the specimen temperature (thus increasing the thermal vibration of the crystal lattice) has a very great influence on defect migration; in general we can say, therefore, that self-annealing might be feasible if the specimen temperature is high during irradiation or annealing after irradiation is possible by raising the specimen temperature after the damage has occurred.

The changes in graphite properties which occur during irradiation are:—

Changes in mechanical properties.—Irradiation increases the hardness and mechanical strength of graphite but makes it more brittle. For example increases in Young's Modulus by factors of 2 or 3 occur after prolonged irradiation at room temperature. These changes do not cause any special problems in reactor design.

Changes in electrical properties.—Marked changes can occur in electrical conductivity, but this is of no importance in reactor core design. They may provide a useful means of observing changes in irradiated graphite specimens because of the inherent accuracy of electrical measurements.

Thermal conductivity changes.—Neutron bombardment can produce very large changes in thermal conductivity; these changes occur very rapidly initially and then more slowly as irradiation is prolonged. Decreases in thermal conductivity by as much as a factor of 50 for an irradiation of 10^{21} n/cm^2 at room temperature have been observed. At the high temperatures (approximately 300°C) typical of the core of a power reactor, the irradiation effects will be much lower, but this process has to be taken into account when calculating the graphite temperature in the core both under steady-state and transient behaviour.

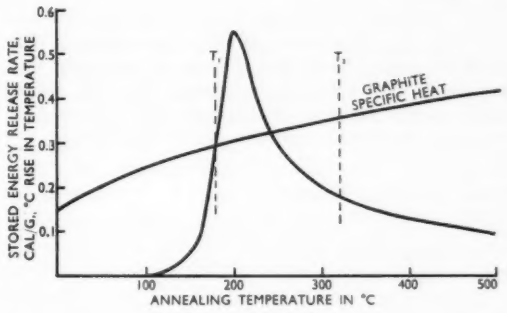


Fig. 1.—Wigner Energy release following low temperature irradiation.

Dimensional changes.—The presence of interstitial atoms between the crystal lattice planes causes an increase in the spacing together with a contraction parallel to the planes. In a single crystal these effects can be very large; in a bulk specimen of artificial graphite where there is incomplete orientation of all the crystals in the aggregate, the effect is qualitatively the same, but quantitatively much reduced. The presence of voids in the bulk material (density approximately 1.75 g/cm^3 instead of 2.25 g/cm^3 for a single crystal) also tends to reduce these effects.

In bulk specimens of artificial graphite, growth occurs perpendicular to the extrusion direction, or parallel to the pressing direction for pressed specimens. In the other direction(s) the effect is small and may be either an expansion or contraction. It is therefore possible to leave gaps for growth between the graphite blocks of a reactor core, while still retaining a firm structure, by placing a double layer of " tiles " between successive layers of blocks. The tiles have their direction of minimum growth " crossed " and at right angles to the graphite column. It is then the tiles which determine the column spacing (one in one direction and the other in the perpendicular direction) and which bear the lateral restraining forces exerted on the core.[5]

Stored energy.—The damage to the crystal lattice is accompanied by a storage of energy since recombination of interstitial atoms with vacant lattice positions leads to

an energy release. Typical figures for the energy storage at various irradiations (irradiation temperature 30°C) are shown in the following table:—

Irradiation (n/cm²)	0.5×10^{21}	1.0×10^{21}	1.5×10^{21}
Energy (cal/g)	250	400	500

These figures are to be compared with the specific heat of graphite (0.2 to 0.4 cal/g, °C varying with temperature); for example after an irradiation of 1.5×10^{21} n/cm² there is enough energy stored to raise the graphite temperature by about 1,500°C, should it all be released instantaneously. Also, in the centre of a power reactor core, 1×10^{21} n/cm² corresponds to about one year of operation. It is clear that energy storage is a subject which must be studied in detail by the reactor designer.

The two aspects of this problem on which information is required are:—

(a) How does the total energy storage for a given neutron irradiation depend on the graphite temperature during irradiation?

(b) When energy is stored in graphite, in what way is it released?

It turns out, when this problem is examined, that (b) should be treated first; the designer is then able to state (needless to say with a large safety factor) the maximum energy storage that can be allowed, and a procedure for preventing an unsafe condition can be laid down.

Release of Stored Energy

It is instructive to consider first the results of irradiation at low temperatures (e.g. ~30°C). Fig. 1 shows a typical form of the energy release rate versus temperature when the specimen is irradiated at about 30°C and subsequently annealed. (It corresponds to a total neutron dose of about 0.5×10^{21} n/cm².) It is seen that the energy storage can be very roughly divided into two parts: there is a "low temperature" component which has all been released when the specimen is raised to about 300°C and a "high temperature" component which is only gradually released as the temperature is further raised and whose release is very roughly proportional to the amount of temperature rise.

The curve of the specific heat of graphite as a function of temperature has been plotted on the same figure. It will be seen that if external heating is applied so as to raise the graphite temperature to point T_1 (about 180°C), then the specimen temperature will rise spontaneously to T_2 (about 320°C) where the two shaded areas are equal. Following such a release of energy, it would be necessary to raise the graphite temperature above T_2 before any further release could be obtained. The best way to describe the situation is to say that above T_2 the effective specific heat of graphite would have been reduced somewhat below its normal value. Any reactor transient which involved the input of heat into the moderator would produce a rather larger temperature swing than for an unirradiated system but this effect would only occur if the graphite temperature exceeded 320°C, i.e. 290°C above its normal temperature.

In essence this is the method which was used at Windscale and in the more recent "release" carried out on BEPO at Harwell. The conclusion to be drawn from the "Windscale incident" is not that the method is essentially dangerous, but that very complete instrumentation is necessary to measure temperatures in the core so that the whole operation can be carefully controlled. The differences between Windscale and BEPO and details of the methods are given in the Final Report[6] of the Technical Evaluation Committee on Wigner energy problems set up following the Windscale accident.

In a power reactor the irradiation temperature is higher and the form of the energy release curve is quite different. It is shown (slightly idealized) in Fig. 2. If the energy has been stored at temperature T_0 then there is no release of energy until the specimen temperature has been raised to a temperature T_1 which is 50 to 100°C above T_0; above T_1 the energy release rate is more or less independent of temperature up to a temperature of about 1,500°C. (There is, in fact, probably a peak in the region of 1,000 to 1,500°C but this is of little practical significance.) By the time about 1,500°C has been reached, all the stored energy has been released.

There is, thus, no hazard caused by the possible triggering of the release of a "low temperature" component since this no longer exists but, conversely, annealing has been made very much more difficult since there is no mechanism for spontaneous rise of temperature unless the energy storage is very high. In such a case the situation is dangerous since, if the energy release rate is greater than the specific heat near the threshold for release, it is likely

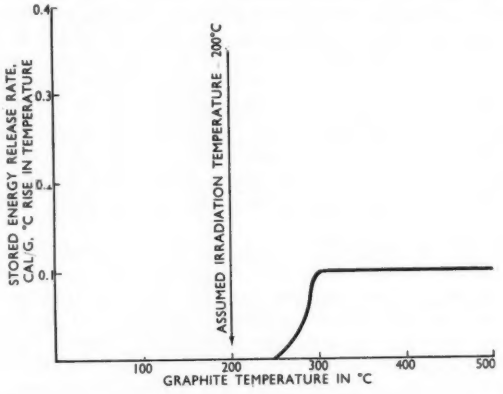


Fig. 2.—Wigner Energy release following irradiation at 200°C. (Total stored energy=120 cal/g.)

to be so at all temperatures and, if the reaction is started, it will carry the graphite up to a temperature of (say) 1,500°C.

In other words, the Windscale-BEPO method cannot be adopted for a power reactor where the graphite is operated at an elevated temperature.

To calculate the energy release rate the simplifying (and pessimistic) assumption may be made that the release begins at (say) 50° above the irradiation temperature and that the release rate is constant from this up to 1,500°C when it falls to zero. For a total storage S cal/g at an irradiation temperature T_0 the release rate will be given by:—

$$dS/dT = S/1500 - T_1 = S/1450 - T_0$$

A hazard from the stored energy would exist for values of dS/dT greater than the specific heat of graphite (approximately 0.3 cal/g, °C).

For example, if $T_0=250$°C, S must not be greater than 360 cal/g as the limit of energy storage for safety. Applying an appropriate safety factor we then arrive at a practical figure to use in design.

The next question which arises is how this figure is to

be used. There are two approaches which can be adopted: the first is to arrange the necessary equipment so that periodic controlled energy releases can be carried out as required; the second is to adopt the old cliché that "prevention is better than cure" and to design a core in which the graphite temperature is sufficiently high to prevent significant energy storage during the life of the reactor so that no releases are necessary.

The second of these solutions is the one that is now generally adopted because of certain difficulties about the first method. These difficulties may be illustrated as follows (Fig. 3). Suppose we have a reactor with a gas

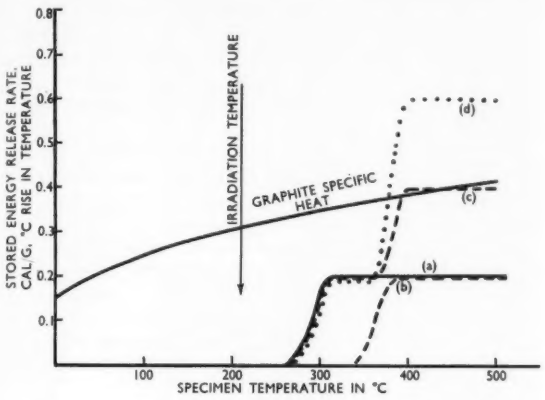


Fig. 3.—Energy release rate against temperature for various conditions.

(a) Irradiation to storage of 250 cal/g. (b) As (a) followed by annealing at 350°C. (c) As (b) followed by an equal irradiation. (d) As (c) annealed at 350°C, followed by further irradiation.

inlet temperature of 200°C so that the graphite temperature at the base of the core is about 210°C. To carry out a Wigner release we must raise the temperature by, for example, increasing the gas inlet temperature. It is unlikely that this can be raised much above (say) 350°C, due to difficulties with the steel support structure, etc., so, by annealing, we raise the safety margin on temperature from about 50°C (with no anneal) to 140°C.

This increased safety margin is of value, certainly, but it is not as high as one might hope. Furthermore, after several annealings followed by re-irradiation we shall ultimately reach the stage shown in curve (d) of Fig. 3 where the annealing process may itself prove hazardous. This possibility could undoubtedly be overcome if necessary, but the volume of instrumentation required (thermocouples and recorders, etc.) would approach alarming proportions.

Provided that the graphite temperature is sufficiently high the energy storage saturates at a low level (Fig. 4). Owing to the very strong temperature dependence of the self-annealing rate, the saturation temperature depends only very slightly on the neutron flux level (an increase of a factor of 10 in flux raises the saturation temperature by only about 25°C). The core designer thus has to ensure that the graphite temperature is at all points near or above the saturation temperature so that significant energy storage is prevented.

Considering a reactor with a gas inlet temperature of 200°C and an outlet temperature of 400°C no special design measures are necessary to prevent energy storage in the upper half of the core where the gas temperature

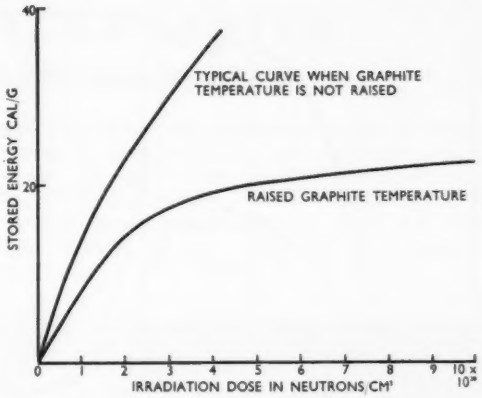


Fig. 4.—Effect of temperature on energy storage.

is high, only in the lower 6 to 8 ft of the core is it necessary to raise the graphite temperatures above the "normal" values appropriate to an inlet gas temperature of 200°C. The target is in the region of 250°C to 300°C.

Possible methods of attaining this result would be to:—

(1) Raise the gas inlet temperature.

(2) Recirculate hot gas through a special circuit and special channels through the graphite.

(3) Provide electrical heating of the lower part of the core.

(4) Use nuclear heating to raise the graphite temperature.

Of these methods, the first leads to great economic losses, since either the channel rating must be reduced (the maximum fuel can temperatures being fixed) or else the blower power must be enormously raised in order to increase the flow of gas; the second requires much additional expensive equipment (even if it were practically feasible, which is doubtful) and lowers the thermodynamic efficiency of the system; the third is expensive in equipment (even if feasible) and would lead to a substantial loss of efficiency; the fourth method is the only satisfactory method so far proposed.

Nuclear Heating

Nuclear heating of the graphite is obtained in the following manner: roughly 6 to 8% of the energy from fission appears as heat in the graphite since virtually all the neutron energy is dissipated in the graphite during the slowing-down process and in addition some of the gamma radiation from the various nuclear processes is absorbed. If the graphite is in contact with coolant gas this energy production gives no significant result but if the graphite is insulated from the coolant flow then the heat has to be transmitted by thermal radiation or conduction across the insulating barrier and this results in a substantial rise in graphite temperature.

Graphite Sleeves

In the Hunterston power station being built for the South of Scotland Electricity Board the design incorporates graphite sleeves stacked on each other in the fuel channels to provide individual support for the fuel elements; in the original proposals gas was to be passed up the annulus between the outside of the sleeve and the hole in the main moderator block. To raise the graphite temperature it is only necessary to close the annulus at the bottom of the core since it is possible to make the sleeve of graphite

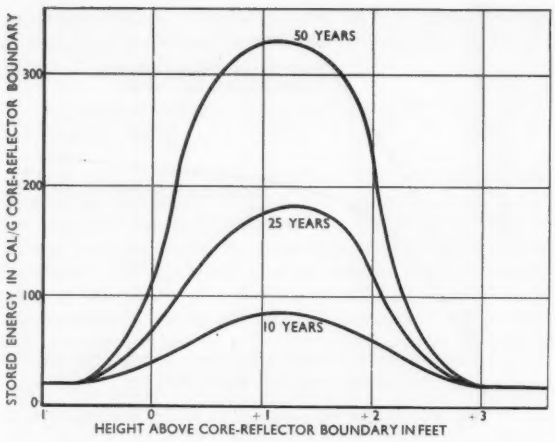


Fig. 5.—Hunterston Wigner Energy storage at worst position in main moderator.

impervious to gas; an insulating barrier of stagnant gas is thus obtained across which the heat from the main moderator must be transmitted by thermal radiation or by conduction. There is inevitably some leakage of gas between sleeves, since perfect contact is unlikely, but this only causes a significant flow of gas in the upper part of the core where energy-storage does not occur.

Energy storage will still take place in the graphite sleeves since they are in contact with coolant on their inner surfaces but they have only a limited life in the reactor, being discharged with the spent fuel, and if it is desired to re-use the sleeves it is a straightforward matter to carry out a complete Wigner release on each sleeve in a small furnace before recharging into the reactor.

It is not essential, in using a sleeve to prevent Wigner energy storage, that it should be made of graphite, and it has been announced that in the Calder and Chapelcross No. 1 Reactors the sleeves will be of Magnox. Since the upper parts of the graphite structure would be sufficiently hot without sleeving and more particularly since the use of Magnox sleeves throughout the core would lead to an unacceptably high absorption of neutrons (the reactor would probably not operate at all), the sleeves will only be used in the bottom reflector and the lower one or two fuel element positions. In these positions the neutron flux is low so that the importance of neutron absorption is very much reduced, nevertheless the presence of additional absorber is likely to produce a significant drop in output. In the three later Chapelcross reactors, the output loss will be avoided by the use of graphite sleeves.

In the other civil reactor designs which did not originally incorporate sleeves it seems certain that this solution of the Wigner storage problem will also be adopted. No announcement has yet been made of the type of sleeving to be used; clearly graphite sleeves are preferable, since they do not involve loss of output, but whether or not they can be incorporated at a late stage depends on the details of a particular core design.

The present semi-empirical methods used by the core designer (in preference to full theoretical treatments as yet not completely verified by experiment) are known to be pessimistic in their predictions of energy storage. Proper account is not taken, for example, of radiation annealing, i.e. the effect of local " hot-spots " in the crystal lattice caused by neutron collisions which help to anneal existing damage. In time, therefore, the present temperature restrictions may be somewhat relaxed. Even on the present basis it would take 50 years before the energy storage in the worst position in the Hunterston core (Fig. 5) necessitated a Wigner release. Similar figures can be quoted for the other stations.

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L'Emmagasinement d'Energie Wigner dans le Graphite

Le phénomène d'emmagasinement d'énergie Wigner dans le graphite est devenu à l'heure actuelle bien connu en ce qui concerne ses principes généraux, mais des problèmes supplémentaires se posent en matière de la marche des réacteurs aux températures élevées. Il se présente des difficultés à l'égard de la libération contrôlée de l'énergie, et on a tendance à dessiner des modèles prévoyant une température de graphite suffisamment élevée pour empêcher des emmagasinements d'énergie appréciables pendant la durée du réacteur. Cela peut s'effectuer au moyen d'une certaine forme de manchon, soit en graphite ou en magnox, laissant un espace annulaire qui se remplit de gaz stagnant, en réduisant ainsi le transfert de chaleur du graphite et en élevant sa température à un niveau approprié. L'emploi de graphite est préférable, vu que la perte de neutrons sera appréciablement plus réduite et que des manchons de magnox ne s'emploieraient que pour la partie inférieure du noyau.

Die Aufnahme der Wigner Energie in Graphit

Das Phänomen der Aufnahme der Wigner Energie in Graphit ist mit der Zeit nichts Neues mehr, soweit es sich um die allgemeinen Grundsätze handelt, jedoch entstehen neue Probleme, wenn Reaktoren mit hohen Temperaturen arbeiten. Die Schwierigkeiten, die auftreten, beziehen sich auf die Kontrolle der Freimachung der Energie, und zur Zeit ist die Tendenz, die Konstruktion für eine Graphit-Temperatur zu entwerfen, die hoch genug ist, um irgendwelche bedeutendere Energie-Aufnahme während der Lebensdauer des Reaktors zu verhindern. Dies kann durch eine Art Schutzhülle von Graphit oder " Magnox " erreicht werden, die einen ringförmigen Raum freiässt, der mit ruhendem Gas gefüllt ist, wodurch die weitere Wärme-Uebertragung vom Graphit reduziert wird, was dann zu einer Steigerung der Temperatur bis zu einer angemessenen Höhe führt. Die Verwendung von Graphit wird vorgezogen, da dann der Verlust von Neutronen bedeutend geringer sein wird, sodass " Magnox " Schutzhüllen nur für den unteren Teil des Kerns Verwendung finden würden.

Almacenamiento de Energia Wigner en Grafito

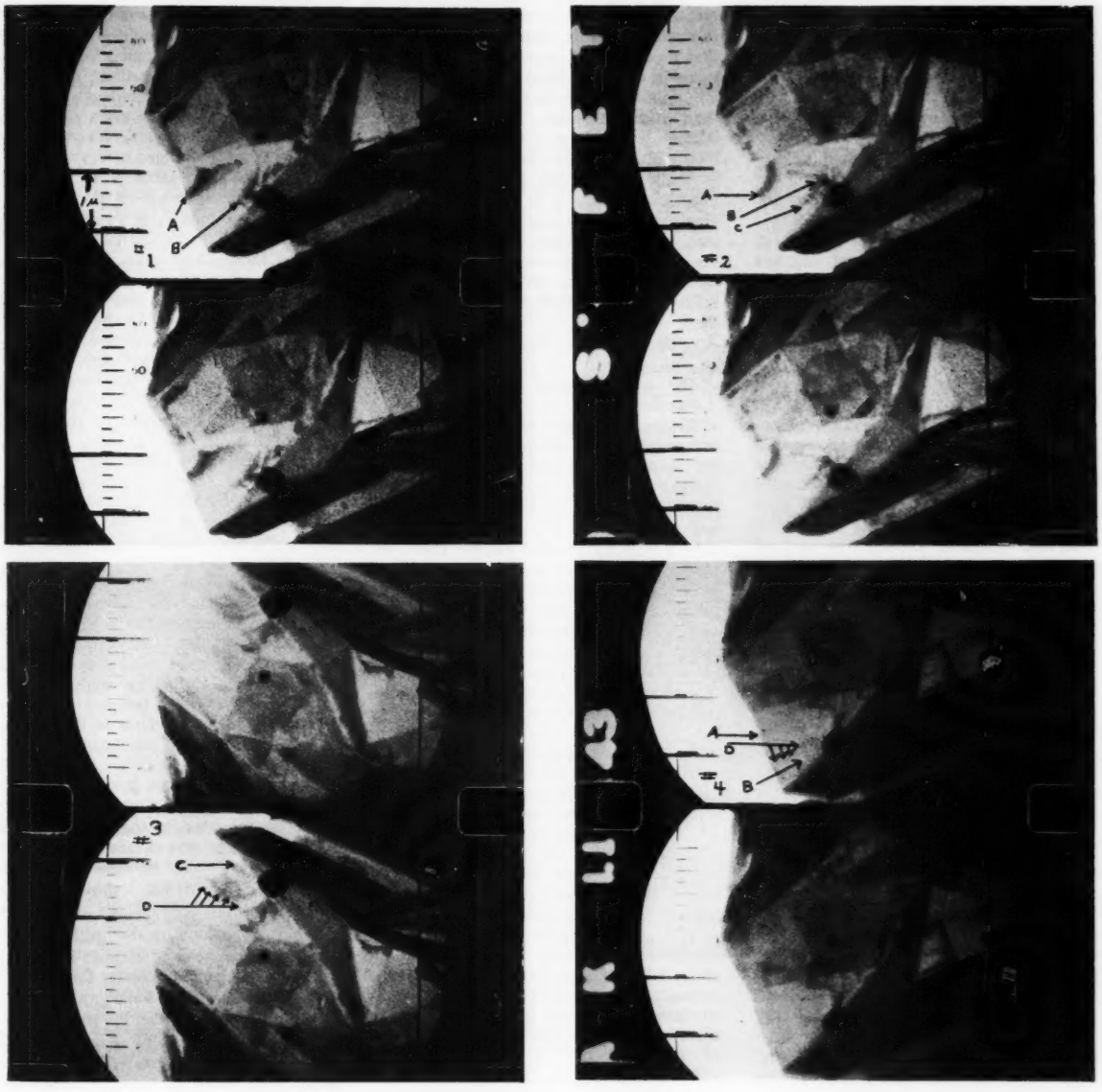
El fenómeno del almacenamiento de energia Wigner en grafito es ya muy conocido en cuanto a los principios generales se refiere, pero surgen problemas adicionales con la operación a altas temperaturas de reactores. Existen dificultades con relación a la liberación controlada de energia y la tendencia es diseñar para una temperatura de grafito suficientemente elevada para evitar el almacenamiento significante de energia durante la vida del reactor. Esto puede ser efectuado con alguna forma de manguito, ya sea de grafito o de " magnox," dejando un espacio anular que se llena de gas estancado, asi reduciendo la transferencia de calor del grafito y elevando su temperatura a un nivel apropiado. El uso de grafito es preferible desde que la pérdida neutrónica será considerablemente menos y los manguitos de " magnox " se emplearían únicamente para la parte inferior del núcleo.

DISLOCATIONS IN GRAPHITE

Electron Microscope Studies by Atomics International Inc.

DISLOCATIONS, or imperfections, in the atomic arrangement of the structure of graphite have been recorded for the first time by motion pictures at Atomics International, a division of North American Aviation, Inc. The information was released by Dr. Alexander Grenall at a recent meeting of the Electron Microscope Society of America, at Santa Monica, California.

Dislocations affect the physical properties of materials, influencing the strength, conductivity and other mechanical properties. Dr. Grenall has classified dislocation motions as rapid or slow; rapid movements being jerky and completing their action almost instantly, while slow motions involved gradual drifting. Differing movements were associated with a single dislocation or a network.



Interpretation of Results

Fig. 1 shows at "A" a dislocation which moves to the right to engage the strain field of dislocation "B." Fig. 2 shows an intermediate stage of the interaction of dislocation strain fields, "A" and "B." The stress generator is "C." Fig. 3 shows how the strain fields of dislocations "A" and "B" have merged to activate the stress generator at "C" and produce a series of dislocation loops, "D." Fig. 4 shows how the dislocations have all moved out of the crystal to leave the material more transparent to electrons than before. Note the absence of dislocations "A" and "B" and those previously indicated at "D." These examples are representative of Dr. Grenall's observations.

The American Nuclear Society

Winter Meeting Reviewed

By J. M. HARRER
(Director of Engineering, Argonne National Laboratory)

ON December 8, 9 and 10, the American Nuclear Society gathered in Detroit, Michigan, for their Winter Meeting at the Sheridan-Cadillac Hotel. Some 900 registrants were treated to a diet of papers covering almost every phase of nuclear engineering. A cold, hard snowstorm discouraged outside activity, and the sessions were well attended; for the most part, lively discussion took place.

R. L. Murry and M. A. Schultz proposed an irradiation charge formula for a testing reactor as an alternate to the standard $55/10^{20}$ nvt-in.[3] levied at the Materials Testing Reactor. Their charge formula makes a distinction between fast and thermal neutron flux. Charges must refer to actual neutrons available and they proposed some offsetting credit be given to users inserting fuel elements for test.

The ever-popular subject of safety was covered in its many different aspects. In two papers, the TRIGA reactor was discussed. The prototype of this research unit, which is water-cooled and zirconium hydride moderated, has operated since May 3, 1958. It contains 54 fuel-moderator elements, totalling 2 kg, U^{235}. Transient response experiments showed that a maximum power of 250 MW was reached when a $2 reactivity step was inserted. This released 10 MW sec at a maximum fuel temperature of 360°C. This was some 50 MW less than the peak reached in the SPERT-I unit prototype of the familiar swimming-pool reactor. It was pointed out that because of the inherent built-in safety in this reactor, the transient tests were controlled and instrumented at a panel only about 30 ft from the top of the operator pit located in the same room.

A series of papers were presented by the SPERT staff in which analytical and empirical formulæ were developed for explaining the inherent shutdown mechanism of the swimming-pool type reactor cores. S. G. Forbes pointed out that the shutdown effect was complicated by phenomena still not well understood. A simple model in which the shutdown effect is proportioned to the energy released up to any instant is not satisfactory for this inhomogeneous type core. This basic idea, however, was shown satisfactory for the TRIGA reactor, because it conforms more nearly to the assumed homogeneous conditions.

Progress in work with a reactor safety device generally referred to as a "fuse" was described by S. H. Fitch. The effective reduction in peak power using this "fuse" was between ½ and 1/25 of the peak power reached under self-limiting conditions in the swimming-pool type reactor. Total energy release was generally reduced by a factor of 10 from the self-limiting case. The fuse action is set off by an enriched-uranium loaded cap which, due to heating by high flux, first releases the pressure in an intermediate chamber filled with helium gas. BF_3 gas at an even higher pressure is then released through rupture diaphragms behind which it was restrained by the intermediate pressure helium. The device is ready for use, but many of the techniques of applying it to an operating reactor have not been worked out. It was pointed out that some method of testing the fuse was needed to assure an operator that the BF_3 had not been released before starting operation. To date, the device is experimental and developmental, and has not been applied in routine operation as a safety feature in the swimming-pool reactors for which it was designed.

Reactor concepts were presented in two sessions. R. E. Schreiber described the nuclear rocket propulsion work being carried out at project "Rover." Debugging work on this nuclear rocket test stand was well along, although no date is now set for first nuclear tests. At present, the principal effort is directed toward testing the remote disassembly equipment. The project is characterized by short life requirements for core materials under unusually high temperature conditions. Gas is passed directly through the core and the rocket impulse is obtained from the rapid heating of the gas.

T. C. Merkle took the nuclear propulsion work further out into "orbit" with a discussion of nuclear rocket capabilities. He pointed out that space travel outside of the gravitational earth pull was most practical with an ion propulsion rocket. He preferred this method to several others, which suggest themselves, such as gas discharge, explosives, recoil rockets, etc. To develop power for the ion rocket, electrical generating plants weighing about 1 lb/h.p. were shown to be as well within feasibility. The possibility of thermonuclear power being used in space travel, presently at least, seemed quite out of the question.

Following up the idea that nuclear heat sources are a basic requirement in space travel, E. Schnetzer and W. R. Corliss described a 1 MW nuclear power package using a closed cycle gas system driving a 400 c/s induction generator at 24,000 r.p.m. The gas-turbine suggested had 12 stages using molybdenum as a principal construction material. The total plant weight proposed was 11,000 lb. An unattended operating cycle of 10,000 hours was possible using present-day technology for construction of hermetically sealed rotating machinery. If the power from this plant was used in an ion propulsion system, it could produce 3.6 lb thrust at a specific impulse of 9,600 sec with a caesium propellant. Properly designed, the systems described might produce the ability to carry out a circuit trip of Mars in 1,000 days. Tickets for the trip were not available, however.

Getting back to earth, S. G. Wildman and A. Norman proposed the use of a reactor to produce a 10^4 γ-radiation dose to a depth of 6 in. for sterilization of agricultural land. This dose would require a neutron flux of 10^{11} n/cm², sec. No reactor designed was proposed, but the present success with the APPR reactor was shown as evidence of feasibility. He suggested that at $70 an acre, radiation sterilization might pay its own way in terms of higher yields of corn, wheat, and sugar beets. Destruction of supposedly helpful life in the ground, such as worms, would not affect the success of the plan.

In a paper by M. Levoy and J. J. Newgard, a marriage of the boiling water and liquid organic, moderator-coolant systems was discussed. The authors proposed to retain the advantages and to overcome the disadvantages of both types by combining the two coolant methods in one package. Improved stability was proposed as the main contribution obtained, principally by matching the negative coefficients of temperature in the organic to the void effects in the boiling water. Damping of oscillations is provided by heat capacity in the organic coolant. An 8 ft core was proposed to provide 250 MW of heat.

An organic moderated fluidized bed reactor concept was discussed by J. H. Wright and V. von Hollen. This concept tagged, "OMFBR" should contain remarkable self-controlling and safety features according to the authors. To raise power, the pump simply stirs up the uranium fuel pellets, raising them into a critical configuration which produces heat to be absorbed by the organic carrier-coolant. Increased heat reduces coolant density and allows the pellets to settle back. The power is lowered as the bed leaves its ideal state of equilibrium. It was clear that the concept still presented many unsolved problems.

The more realistic state of the art was brought out by discussion of the design of N.S. Savannah. This nuclear-powered merchant ship is scheduled for launching next year. The reactor should be critical

in December, 1959. Three passes of the pressurized water coolant are used; two passes being in the active core and one in the reflector. Design is very conservative, burnout being expected at 2.7 times rated peak power density. The design target of 52,275 MWd at normal power of 63.5 MW of heat can be achieved without control other than the 21 boron-10 stainless steel control rods. The fuel is UO_2 sintered to ½-in. diameter pellets at 90% theoretical density. A 0.007-in. gap is provided between pellet and 304 stainless steel tubular cladding. Melting of the oxide is not anticipated at rated power operation.

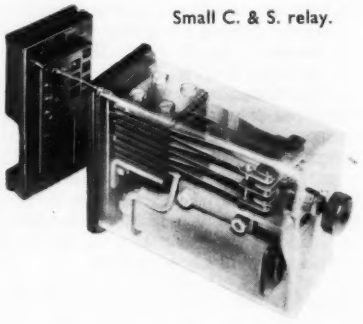
On the lighter side, the participants heard an address by Mr. John F. Floberg at the meeting banquet. Always a diplomat, Mr. Floberg rode a middle course in his talk, stressing the difficulty faced by the AEC in selecting the proper path for America's nuclear power efforts. He pointed out that the Commissioners were anxious to hear ideas on the programme expressed by the Nuclear Society members.

Correspondence

Sir,

THE article "Relays and Reliability," by J. J. Smith, in your January issue, said much that wanted saying, but the writer believes the following will be a useful extension to his theme. The requirements of relays for use in reactor protection circuits differ but little from those long used in the fault alarm circuits that protect generators and boiler plant and it would therefore be wise to examine practices that have evolved from the accumulated experience of operating such safety circuits in conventional generating stations.

One of two relay systems developed specifically for this duty, and approved by the C.E.G.B. and other authorities, is usually employed. The first is made by Standard Telephones and Cables, Ltd., using a special plug-in unit containing up to six G.P.O.-type relays, and the second employs individual plug-in relays specially developed for this duty by Clifford and Snell, Ltd., for which we are the distributors.



Small C. & S. relay.

Both systems have the following features in common:—

(a) Transparent non-inflammable covers attached, not to the socket, but to the relay itself which is therefore protected from dirt and damage at the time it needs it most, i.e., when unplugged and being handled or laying around during installation or fault finding.

(b) The units are not hermetically sealed (hermetic sealing is inadvisable when long life is required with infrequent operation) and the covers have a fixing arrangement which is substantial yet allows quick removal for tests *in situ*.

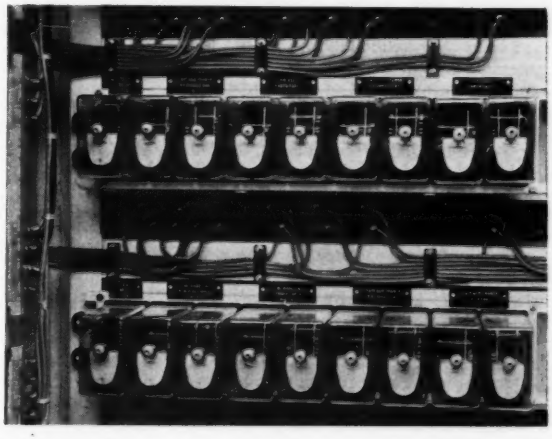
(c) Complete reliability, not only of the relays but of the plug-in facility, proved by extensive operating experience.

Many engineers are understandably cautious about introducing extra connections in the form of plugs and sockets into their circuits as these parts are much less easy to design than they look, but we can say that although very many thousands of C. and S. relays are in service there has not been one single reported case of socket failure.

Relay Adjustment

The techniques of relay adjustment and the tools needed are described and illustrated in the G.P.O.'s Engineering Instructions, B.5144. It may be possible to get a copy but no one should ever touch the adjustment of a relay in an important circuit unless they have undergone a course to acquire the necessary skill and, also, have had sufficient opportunity to keep their hand in. Contact springs or blades are stressed by a "stroking" process and never by bending. A blade once bent, say, by catching it with a wire or the sleeve during installation, cannot easily be made to hold its setting again, and should be replaced.

Skeleton relays are used as standard in very large installations such as the central supervisory system for a group of generating stations as these justify air conditioning and the constant attendance of skilled adjusters. They are also used successfully in small sealed units such as Service radio equipment but it does seem that for many applications between these in size the nature of adjustments does make it advisable to use properly covered plug-in units.



Relay racks for power station service.

Spark Suppression

Perhaps the most effective method with d.c. is to connect a rectifier (current rating immaterial) in reverse across the load. On a.c. the rectifier can be replaced by a solid carbon resistor. It is usually adequate for this resistor to take about a tenth of the steady load current. The more effective the suppression the longer the relay will take to release and, when this is important, suppression should be replaced by magnetic blow-outs on the control contacts.

A.C. Operation

Direct a.c. operation (possible with the C. and S. relays) has several advantages. The coil current is automatically reduced when the relay has operated; any chance of sticking on with a lightly adjusted relay can be avoided by connecting a high resistance across the coil contact so that a small demagnetizing current always flows, and a.c. is kinder on light and slow-moving instrument contacts.

Contact Material

It is all-important to use the right contact material but there are so many variables that it is often difficult to choose the best one. The writer feels that more people should publish their findings in this field.

Experience has shown that silver is not ideal for low voltage non-inductive loads such as indicator lamps, and for this duty 60/40 palladium silver seems to be the most practical material. We have also experienced difficulty with platinum in the presence of hydrocarbon vapour, and suspect that this is due to its strong catalytic action. After all, platinum is used by the oil industry to crack hydrocarbons and Bell Telephones showed recently that nascent carbon can make contacts non-conductive.

This amplification of his article has been seen by Mr. Smith, who agrees with the views expressed.

Yours, etc.,

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Technical Papers and Publications

Institution of Electrical Engineers

Savoy Place, London, W.C.2.; Jan. 15, 1959.

Electrical Installation at Calder Hall Nuclear Power Station. By N. J. Mackay, A.M.I.E.E., and E. Hardwick, A.M.I.E.E., (U.K.A.E.A. I.G.).

Calder is a mixture of the conventional and the unconventional: a number of features quite unlike normal power station practice were, of necessity, introduced, but where standard, well-tried techniques could be used, they obviously were, to minimize the departure from conventional methods.

Maximum security of supply was, a fundamental, the criterion and (since the control rod withdrawal rate is limited) the length of time needed for re-start made the avoidance of spurious tripping another important feature. This, of course, led to departure from the normal unit system of supply in that loss of generation could not be allowed to shut down the reactor supply. This, then, was given by duplicate station transformers, backed up by generation from two alternators, each being driven from a different reactor. Full dumping facilities were provided so that reactors could be maintained in service even when the generators were shut down. It was, in short, necessary to ensure that the reactors could be controlled and cooled, whatever happened. Furthermore, the station auxiliary load was approximately 17% of the generated output—a very high figure for a power station—most of it absorbed in the blowers. The arrangement of the station is unusual in that the main switchboards are located at the reactors, instead of near the turbine house, as is usual in conventional stations. This has enabled each reactor to be treated as a self-contained unit for both normal and emergency supplies, the latter consisting of batteries and diesel generators. This arrangement, incidentally, proved valuable for blower testing.

The Calder generators are rated at 23 MW C.M.R., but are limited to 21 MW by the design figure for the turbine. The "A" and "B" stations, although each containing four generators, differ slightly in arrangement in that whilst in "A," they are connected to supply the "house" requirements (and export any surplus to the grid) the second pair supply the grid in "B" station only, whilst in "A," they are connected to supply Windscale. The main switchgear for these generators is actually located at Windscale, and a local control board feeds back indications to the central control room at Calder "A." (The control for both stations will eventually be transferred to Calder "B," where a single control room will give centralized control of 132, 11 and 3.3 kV circuits.)

Interlocks

Apart from the arrangement of main supplies, there are a number of interesting interlocking and safety arrangements. The blowers, for example, are fitted with d.c. pony motors capable of running the blowers at 10% full speed, for emergency shut-down cooling, and these are arranged to start (and mechanical clutches engage) when the main blower circuit breaker trips. Faults requiring shut-down of the blower are initiated by tripping this breaker, and inter-tripping is arranged so that if one blower on a reactor trips, the other three also shut down to avoid reversal of gas flow. Comprehensive interlocking and automatic start arrangements are provided on the blower auxiliaries, so that pumped supplies of bearing lubrication and seal oil, with their associated coolers and fans, are maintained.

Control Rod Mechanisms

The control rod mechanisms are driven by synchronous motors with 3 ph. stators and unwound variable-reluctance rotors capable of locking into step with frequencies of 1.33 c/s (fast in) 0.133 c/s (normal in), 0.0133 c/s slow out or 0 c/s (held stationary). The variable-frequency supply is obtained from a rotating frequency converter set. A small number of mechanisms can be connected to a separate potentiometer system for trimming control.

Standby Supplies

Main source of standby supply is a 240V battery rated at 1950 Ah normally supplied from a 400 kW rectifier unit. Should the a.c. supply fail, the battery, which normally floats, can carry the d.c. load for 30 min. The diesel generators (2—500 kW) start up automatically with a.c. failure. The possibility of boost-charging voltages up to 330V has necessitated the supply of stabilizing devices on the emergency lighting.

The authors point out that insufficient time has elapsed to draw any firm conclusions on the behaviour of the installation under full operating conditions, except that the provision of duplicated supplies to each reactor has been valuable in cases of loss of a feeder.

Cabling space, although considered ample in the earlier stages, has proved a problem. Subways around the reactor have proved of considerable value, but it is felt that an increase in the size of the cable mezzanine for the central control room would have been of value. The blower houses also presented cabling problems due to lack of space. The magnitude of the cabling problem should not, it is felt, be under estimated for future stations with combined control rooms.

Institution of Chemical Engineers. Meeting at the Geological Society, Burlington House, W.1; Jan. 6, 1959.

The Treatment of Water for an Industrial High Pressure Boiler Plant. By J. Arthurs, M.Sc., A.R.I.C., J. A. Robins, B.Sc., A.C.G.I. D.I.C., A.M.I.C.E., T. B. Whitefoot, B.Sc., A.M.I.C.E.

At the Wilton Works of Imperial Chemical Industries Limited, high pressure boilers combined with a back pressure turbine installation supply steam and electricity for operation of chemical plants. The direct usage of steam in certain of the chemical manufacturing processes, and unavoidable losses of condensate due to contamination, result in heavy demands for treated water for boiler feed purposes. Raw water of potable quality and raw water blended with fresh river water are treated to produce 1.3 million gallons per day of feed water suitable for boilers operating at 950 lb/in.^{2} gauge and 1700 lb/in.^{2} gauge. The treatment processes and methods of boiler water conditioning are described in this paper and associated boiler and generating plant operating experience is reviewed.

Feed Water and Boiler Water Standards in the Central Electricity Generating Board. By R. L. L. Rees, M.A., M.I.C.E., F. J. R. Taylor.

A fair measure of standardization has now been achieved in the chemical and engineering aspects of the new feed systems of the Central Electricity Generating Board. Such standard systems lend themselves well to a single scheme of water treatment, which can, however, be adapted when necessary to suit any individual plant according to its behaviour. A scheme of water treatment which has been formulated to suit these new plants is described in this paper. Its performance, related to the results of fundamental research, will lead to improvements in theory and technique.

Institution of Mechanical Engineers

Strength at Elevated Temperatures of Aluminium and Certain Aluminium Alloys. By N. P. Inglis, Ph.D., M.Eng., M.I.Mech.E., E. C. Larke, A.M.I.Mech.E.

Short-time data covers a temperature range of 20°-250°C, the stress-rupture curves, which mostly extend up to 10,000 h, relating to temperatures of 100°, 150°, 200°, and 250°C. Creep tests, a number of which were taken into the tertiary stage, have been carried out at 200° and 300°C for the 1½% manganese alloy and temperatures employed for the HE30 alloy were 100°, 150°, and 200°C. Stress-rupture tests still in progress and creep data for the remaining three materials will be reported in an addendum.

NEW BOOKS

Nuclear Reactor Shielding. By J. R. Harrison, M.A. (Oxon.). (No. 4 of the *Nuclear Engineering* Monographs. 68 pp., 39 illus. Temple Press Limited. 10s. 6d. net.)

"Art" (i.e. inspired guesswork) is no longer sufficient for the design of reactor shielding, which has been placed on a scientific basis and is susceptible of solution by more exact methods. While it is obviously not possible, in the space of this Monograph, to give a complete treatment of the theory of reactor shielding, the author has succeeded in giving an excellent brief survey of the field. The introductory chapter outlining the problems to be encountered, and a "refresher" on radiation units and maximum permissible levels, is followed by a review of the theory of gamma attenuation, and an outline of the relevant portion of neutron physics. Shield design proper is dealt with in Chapter 4 which, in addition to the simple problems of source shielding and the more difficult matters of reactor shielding, also deals briefly with the question of designing for minimum total weight. Miscellaneous topics covered in the fifth chapter include special circumstances such as the angular distribution of neutrons leaving a surface, "streaming" as applied to straight and bent ducts and annuli, and the induced activity in various coolants. The book can be recommended with confidence both to those who require an introduction to the subject and those who would wish to use it as a basis for more extensive studies of the shielding problem.

Nuclear Reactor Control and Instrumentation. By J. H. Bowen, B.Sc., A.M.I.E.E., and E. F. O. Masters, B.Sc., A.C.G.I., A.M.I.E.E. (No. 5 of the *Nuclear Engineering* Monographs. 78 pp., 23 illus. Temple Press Limited, 12s. 6d. net.)

This book provides an excellent opportunity for acquiring a sound grounding in a branch of nuclear engineering that is all too often either tucked away as a small section of a general textbook or, when treated as a separate subject, is presented in too much detail for the general principles to be assimilated. The approach is clarified by confinement to the gas-cooled graphite-moderated type of reactor, and the introductory chapter deals not only with the basic principles of the reactor, and the method of extracting power, but the important parameters in control, the control problem under normal conditions, and considerations of safety. Neutron kinetics are the subject of Chapter 2, and the operations of start-up and shut-down are reviewed. Chapter 3 deals with the temperature-stabilized reactor; the "feedback" effects of changes in temperature and reactivity are explained, as well as the transient behaviour of reactors under changing conditions. Chapter 4 is devoted to worked examples, thus ensuring that the principles set forth have been thoroughly understood. Control rods and devices form the subject of Chapter 5, which deals with the investment and effects of control, the calculation of the number required, the available materials, and the specification of actuating mechanisms.

Instrumentation is confined to a single chapter which, nevertheless, manages to give a very good idea of the basic principles of flux measurement, burst-slug detection, and trip circuits, although, of course, it is impossible to give more than the bare outlines in the available space. A bibliography containing 56 references is included.

Steam Cycles for Nuclear Power Plant. By W. R. Wootton. (No. 6 of the *Nuclear Engineering* Monographs. 66 pp., 40 illus. Temple Press Limited. 10s. 6d. net.)

Those who have not studied the subject may find it difficult to realize what a tremendous effect the choice of steam conditions may have on the overall efficiency of a nuclear power plant which, unlike a conventional plant, does not permit random selection of steam pressures and temperatures.

As deputy manager of the atomic energy department of Babcock and Wilcox, Ltd., and as one who was intimately concerned with the optimization of the Calder Hall steam cycle, the author is able to bring a great deal of practical experience to his task of making clear the principles involved even to those who have had no previous experience with steam engineering problems. As would be expected, a large portion of the book is devoted to gas-cooled graphite moderated plant, and the single- and dual-pressure cycles are analysed with considerable thoroughness, the effects of feed heating and reheating being considered, as well as a brief reference to possible future operation at supercritical pressures. Pressurized water, boiling water and liquid metal-cooled reactors are also dealt with. A most valuable feature of this book is the series of appendices which cover the relation between gas outlet temperature and overall thermal efficiency; the use and proper understanding of steam tables; the Mollier diagram; the temperature-entropy chart, the rudiments of turbine efficiency and the problems of exhaust moisture content and, finally, examples of heat-exchanger heat balance calculations.

Radioactivity Measuring Instruments.— A Guide to their Construction and Use. By M. C. Nokes, M.C., M.A., B.Sc. (76 pp., 38 illus. William Heinemann, 10s. 6d. net.)

Elementary radioactive experiments may soon become a normal feature of senior physics in schools. In many cases the necessary instruments can be made in school workshops, but it is necessary to know what one wants, and how much it is going to cost. This interesting and practical little book tackles the problem from this standpoint. Following an introductory chapter on radiation, the G-M tube is described and the characteristics and approximate costs of various types are given. The phenomena in G-M tubes are discussed in some detail. Trigger devices are described in a short chapter, and a further chapter is devoted to power supplies, including rectifiers, stabilizers, transistors and converters. Ratemeters and scalers each have a separate chapter before proceeding to complete instruments and practical hints on construction and testing.

Throughout the book each circuit diagram carries a complete notation of suitable values for components, such as capacitors, resistors and rectifiers, and for each piece of apparatus approximate cost and purchasing references are given for the main components. Where a full description of a circuit is not possible on account of space restrictions, reference is given to other published work.

Sourcebook on Atomic Energy. By Samuel Glasstone. (2nd Edition, 641 pp. D. Van Nostrand Co., Ltd. 34s.)

Many readers will be familiar with the first edition of this classic of atomic energy literature. Others, as the present reviewer, will know it only by its reputation; one that will be carried on by the new volume.

As its name implies, this book presents the basic knowledge necessary for understanding the processes involved in the uses of atomic energy, together with a summary of such uses. More than half the book comes before the chapter headed "Nuclear Fission," but those pages set the idea firmly in context and show clearly what its discovery implied.

Each chapter covers a separate facet of the whole, with the steps in its development in chronological order. The coverage is in each case complete, from the first mention or discovery to around the end of 1957. This means that there is quite frequent reference to later parts of the book, which might be a little confusing to a complete stranger, but otherwise has advantages. The interaction

between different streams of science can be seen, whilst at the same time each stream is kept distinct. Thus the development of our concept of the atom is traced from Democritus to recent measurements of size and mass. Fundamental particles are carried from the sixteenth-century *elektron* to the discovery of the anti-neutron, with a later chapter on cosmic rays and "strange" particles. The story of the utilization of nuclear energy begins with the Curies' realization that radio-active materials were a source of energy, and shows clearly how the discovery of uranium fission led immediately to the possibility of a chain reaction and the utilization at last of the tremendous power by then known to be available in the nucleus. One of the changes from the first edition is the expansion of the section on nuclear reactors into a complete new chapter.

A point of general criticism is that on the technological side the emphasis is rather heavily on American work. The absence of more than brief references to Russian ideas is particularly noticeable and hard to justify in a revision produced long after the first Geneva Conference and appearing just after the second. British work on power reactors is also rather sparsely covered, although Calder Hall is fully acknowledged. This bias is all the more marked since it is completely absent in those parts of the book dealing with the more fundamental aspects.

The treatment is factual, often supported by quotations from original writings, and mathematical only where necessary. As a handy reference to the present status and the past development of atomic energy it is ideal. As a book to be read from cover to cover it serves a double purpose as an introduction to more specialized texts and as a unification of their subjects. It can be highly recommended.—A.G.H.

Nuclear Reactor Metallurgy. By Walter D. Wilkinson and William F. Murphy. (382 pp., 182 illus. D. Van Nostrand Co., Ltd. 42s.).

This book is based on material presented in a course given at Argonne National Laboratory by the authors. The course, sponsored by the U.S. Atomic Energy Commission, is described as being of an international nature. The preface makes it clear that the students had widely varying backgrounds and some of them were unfamiliar with the English language, and the simple style of presentation chosen is designed to assist this type of reader. The authors point out that they were restricted by security considerations, and it is unfortunate that they completed the present manuscript some months before the publication at the Second Geneva Conference of a further large body of information.

Ten out of 20 chapters (or nearly half the book) are devoted to properties of uranium. The other chapters deal individually with the metallurgy of plutonium, thorium, beryllium, zirconium, with liquid metals, ceramics, control-rod materials, radiation damage of non-fissile materials, and finally non-destructive testing of reactor components. From the point of view of readers interested in gas-cooled graphite moderated reactors of the British type, there are major omissions. These include magnesium, graphite, and pressure vessel steels. The authors attempt to incorporate a basic course in some aspects of physical metallurgy in these chapters introducing and discussing briefly such topics as electronic structure, crystal structure, Brillouin zones, and electron/atom ratios, but the reviewer doubts whether readers unfamiliar with a number of the concepts so briefly introduced are much the wiser. A particular example of this is the devotion of three pages to a brief outline of X-ray methods of determining preferred orientation including introducing the concept of the stereographic projection.

In any event the approach could have been carried out more logically. For example in Chapter 3 the authors briefly discuss crystal structures to provide a basis for the material appearing in later pages. In this and subsequent chapters they employ Miller indices to describe crystallographic planes and directions, and then much later, in Chapter 6, they decide it is necessary to define and describe the derivation of Miller indices.

In view of the extensive coverage given to uranium, it is disappointing to find the discussion of creep limited to a page and placed on equal footing with fatigue data. No mention is made of the effect of radiation on the creep of uranium despite the considerable attention this has received by Cottrell and others, since it was first reported experimentally by Konobeevsky at the First Geneva Conference. Irrespective of whether fuel elements are loaded as struts as in the Calder Hall design, the creep properties of uranium are important in relation to the development of theories of swelling due to fission product gases.

The chapters devoted to material other than uranium suffer to some extent from brevity, and from an unnecessary emphasis (in the reviewer's opinion) on methods of production. For example, ore dressing or reduction of beryllium is given four pages, whereas the effect of irradiation is dismissed in four lines, no mention being made of the (n, α) reaction and the possible swelling.

The chapter on ceramics gives one page to graphite, one page to uranium carbide, with no mention of compatibility, and a sum total of four pages to UO_2 on which extensive work has been carried out in Canada, United States, Russia and this country.

In the case of zirconium no mention is made of the importance of removing hafnium or of how it can be removed.

Summing up, this book presents uncritically much valuable material; the emphasis seems to the reviewer to be sometimes wrongly directed and the material is unfortunately dated by work which was released last September at Geneva.—T.J.H.

The British Commonwealth Welding Conference, 1957. (The Institute of Welding, 469 pp., 105s.)

This book contains some 60 different papers presented at the British Commonwealth Welding Conference held in June, 1957. The papers are contributed by notable authors dealing with practically all aspects of welding technology. The subjects covered range from metallurgical problems associated with the welding of the newer and rarer metals to basic production problems, and from reviews of welding techniques to papers on the training of welders, and welding education. Most of the papers emanate from the United Kingdom, but 15 are by overseas authors and the value of the book is enhanced by the inclusion of the discussions which followed the papers.

The publication of this book is frankly designed to augment the work of the Conference, the objects of which were to exchange technical information on welding within the Commonwealth, to consider means of improving the flow of technical information and to emphasize the contribution which welding can make to modern engineering production.

However, a book containing a collection of technical papers usually suffers from a number of disadvantages, since there is bound to be a fair amount of repetition. Many of the papers are unable to deal with some of the more important technical aspects in detail. For example the paper entitled "Application of Welding in the Atomic Energy Field" is excellent up to a point, but it suffers from the drawback of being very short for such a vast subject, obviously because the authors could only give a broad outline of the main points in the time at their disposal.

There are other papers of interest to engineers working in the nuclear energy industry, notably one on the welding of reactive metals. On the fundamental research side, there is a good review of information on the effects of gases on the constitution and properties of ferritic weld metals.

Many of the papers reflect the increasing interest in the welding of light alloy structures and some 10 papers are devoted to this topic. The papers also reveal a surprising number of references to the various submerged-arc and inert gas shielded welding processes, but the reader should bear in mind that most of the fabrication in this country is still being carried out by manual metal arc welding and that authors are often tempted to ride new hobby-horses when asked to disclaim before their learned colleagues.

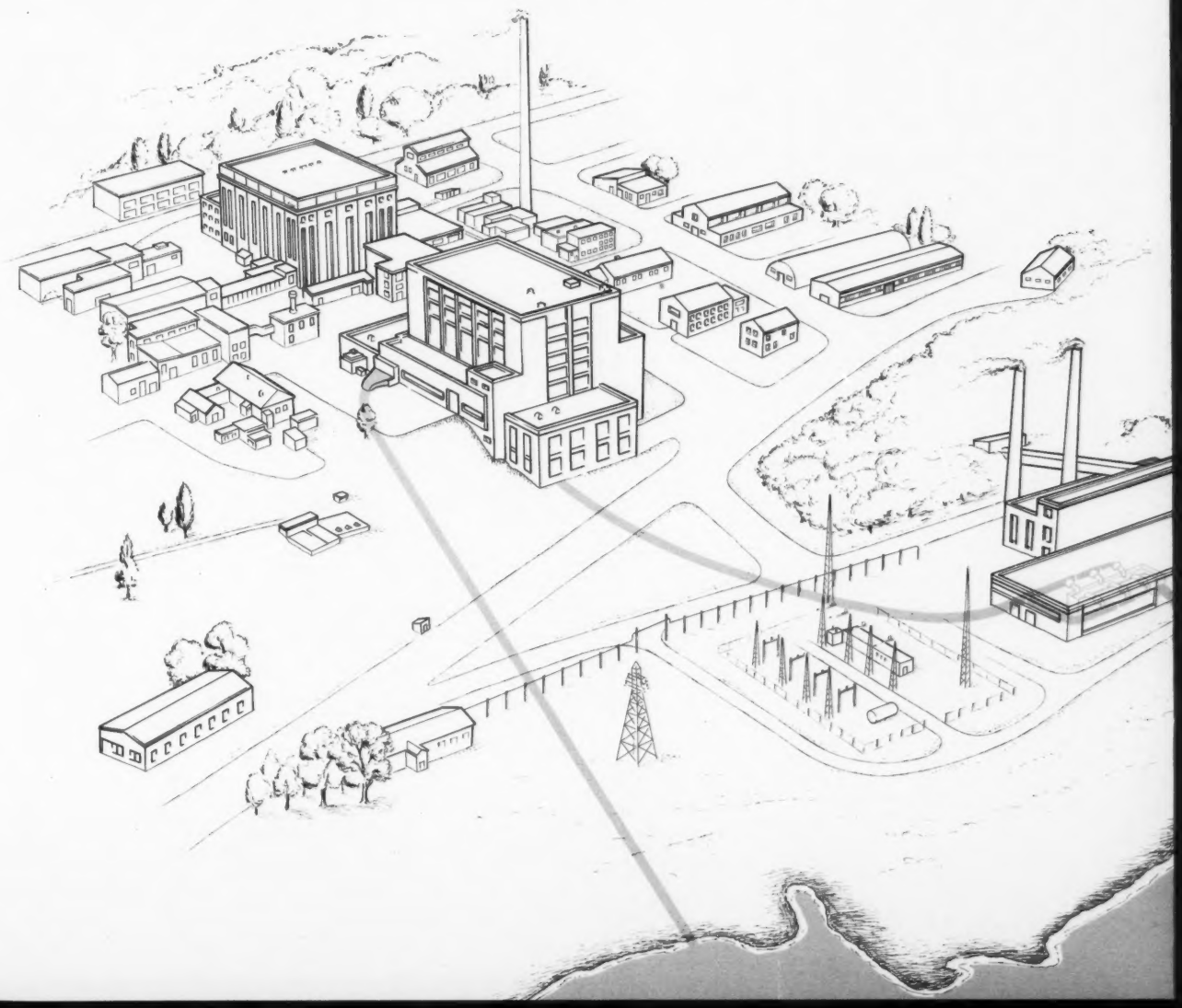
To conclude, this is not a textbook or manual for the practical student of welding. It is, however, a most useful addition to the library shelf for reference purposes.—A.S.A.

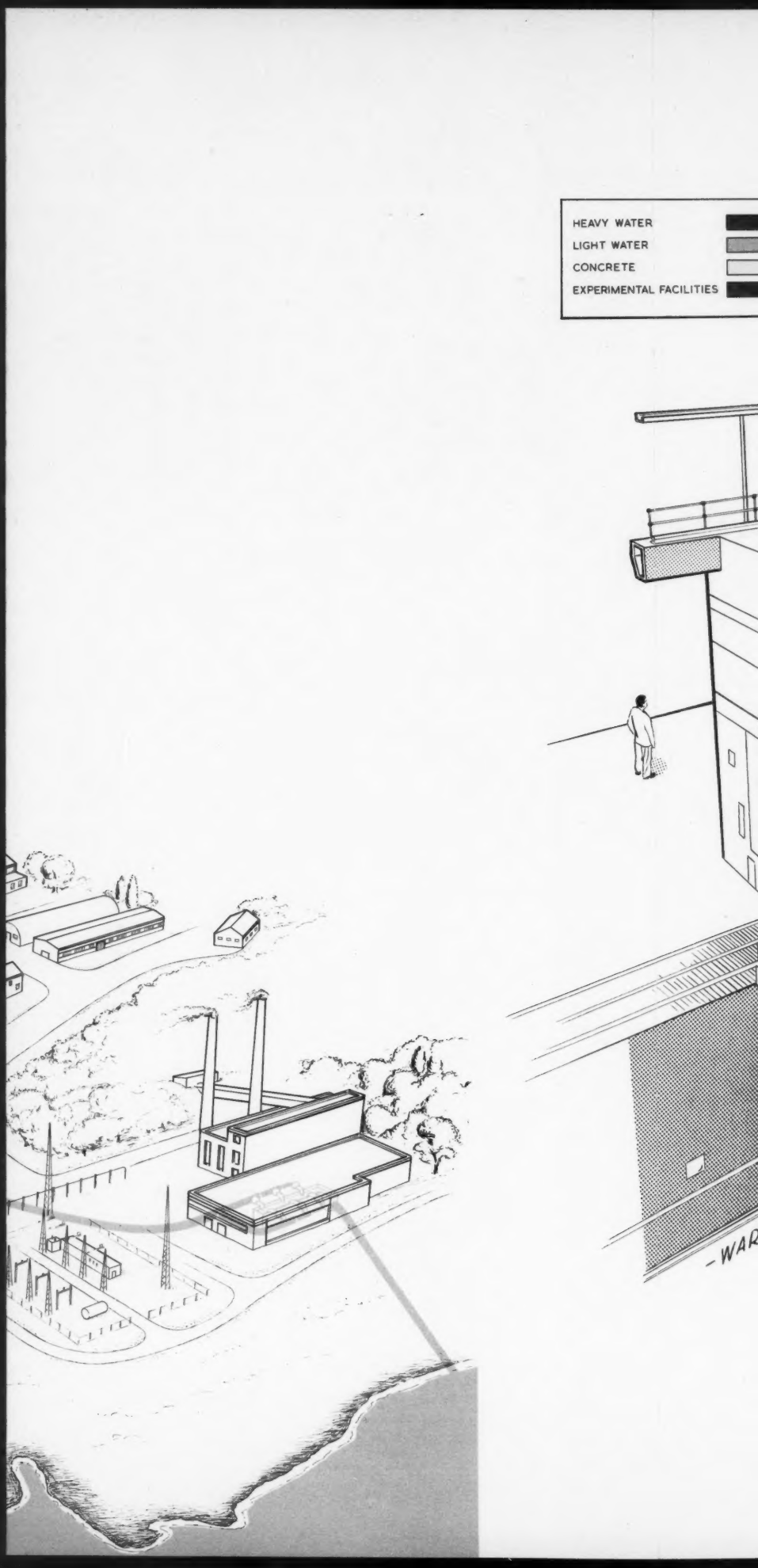
The World's Reactors

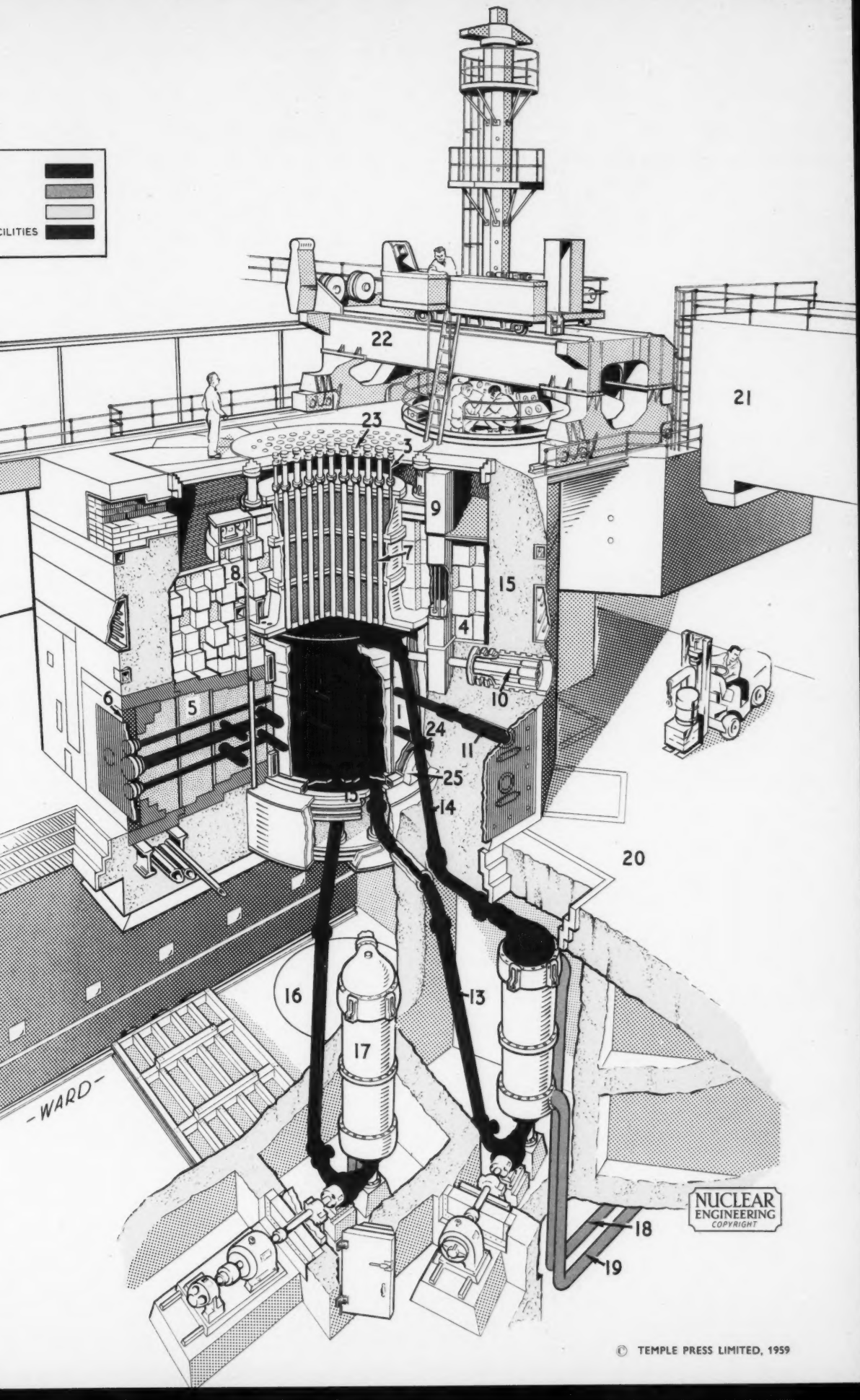
No. 20 NRU

KEY

1. Calandria wall
2. Calandria through tube
3. J-rod
4. Movable blocks of concrete
5. Graphite thermal column
6. Lead door
7. Light water
8. Shutter
9. Gate operating mechanism for experimental hole
10. Ion chamber
11. Experimental hole
12. Re-entrant cans
13. Heavy water inlet
14. Heavy water outlet
15. Concrete biological shield
16. Calandria disposal pit
17. Heat exchanger
18. River water outlet
19. River water inlet
20. Main floor
21. Shielded room
22. Isotope rod flask
23. Fuel rod
24. Light water reflector
25. Steel thermal shield




HEAVY WATER
LIGHT WATER
CONCRETE
EXPERIMENTAL FACILITIES
WAR



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The World's Reactors

No. 20 NRU

TYPE: Thermal heterogeneous.

PURPOSE: Research and materials testing; isotope production.

LOCATION: Chalk River, Canada.

OWNER: Atomic Energy of Canada, Ltd.

OPERATION: Criticality achieved November 3, 1957.

RATING: 200 MW.

CORE: Approximately hexagonal, 11 ft 6 in. diameter.
Active length 10 ft.
Lattice centre 7¾ in. 218 holes.

FUEL: Natural uranium.
Total investment approx. 12.5 U.S. tons.

FUEL ELEMENTS: Five flat strips of aluminium-clad uranium enclosed in aluminium tube.
Width of central strip 5.446 cm.
Width of intermediate strips 4.983 cm.
Width of outer strips 3.109 cm.
All strips 305 cm (10 ft) long.
Thickness of strip 0.434 cm.
Thickness of cladding 0.063 cm.
Total weight of U per element 120 lb.

MODERATOR: Heavy water.
Total investment 58 tonnes.

FLUX: Peak (at core centre) 200 MW: 2.5×10^{14} n/cm² sec.

CONTROL: 16 stainless steel tubes (13 cadmium, 3 cobalt).
Diameter 3½ in.
Length 10 ft.
Rods grouped in banks of 4, 4, 8.
Reactivity controlled by 4-rod banks 0.036.
Reactivity controlled by 8-rod bank 0.074.
All rods dropped simultaneously for scram shut-down.

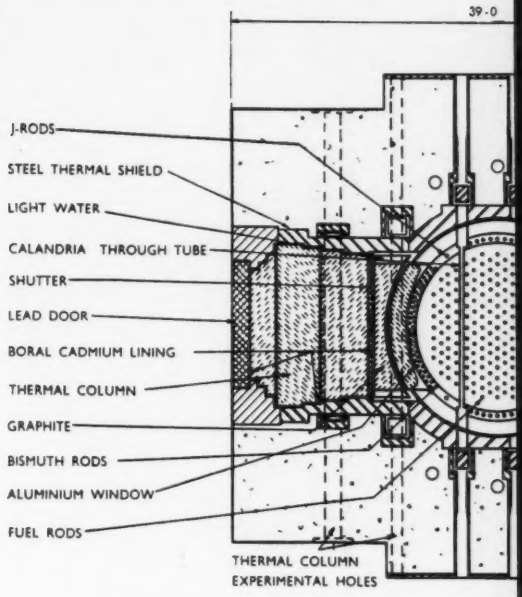
COOLANT: Heavy water circulated through 8 heat exchangers indirectly cooled by a distilled water circuit, secondary heat exchangers being cooled by river water.

Inlet temperature of D_2O	120°F (49°C)
Outlet temperature of D_2O	167°F (75°C)
Max. coolant velocity in core	33 ft/sec
Water circulation	22,000 gal/min (100,000 litres/min)
Maximum heat transfer at 200 MW	630,000 B.t.u./ft², h (199 W/cm²)
Maximum surface temperature	215°F (102°C)
Maximum uranium temperature	370°F (193°C)
Natural water through main heat exchangers	20,000 gal/min (91,000 litres/min)

CALANDRIA:

Inside height (between header blocks)	12 ft (3.66 m)
Inside diameter of reactor	11 ft 6 in. (3.51 m)
Width of J-rod annulus	6 in. (0.15 m)
Inside diameter of water reflector	12 ft 6 in. (3.81 m)
Outside diameter of water reflector	14 ft 8¼ in. (4.48 m)

SHIELDING: Thermal shielding: 12 in. thick cast steel, water cooled.
Concrete shielding 9 ft 6 in. thick using ilmenite ore and magnetite sand.
Density of concrete about 220 lb/ft³.



Sectional plan of reactor. Note slight displacement of core lattice where the horizontal facility passes through.

EXPERIMENTAL FACILITIES:

27 horizontal facilities through the shielding some
diameter. Beam holes provided with cooled
thermal shield.
Thermal column 8 ft sq. at inner end, 10 ft at outer.

ESTIMATED NEUTRON BALANCE:

$\eta_i = 1.326$
$\varepsilon = 1.017$
$p = 0.912$
$f = 0.955$
k_∞ at 20°C $= 1.175$
$L^2 = 0.0147\ m^2$

$L_s^2 = 0.0127\ m^2$

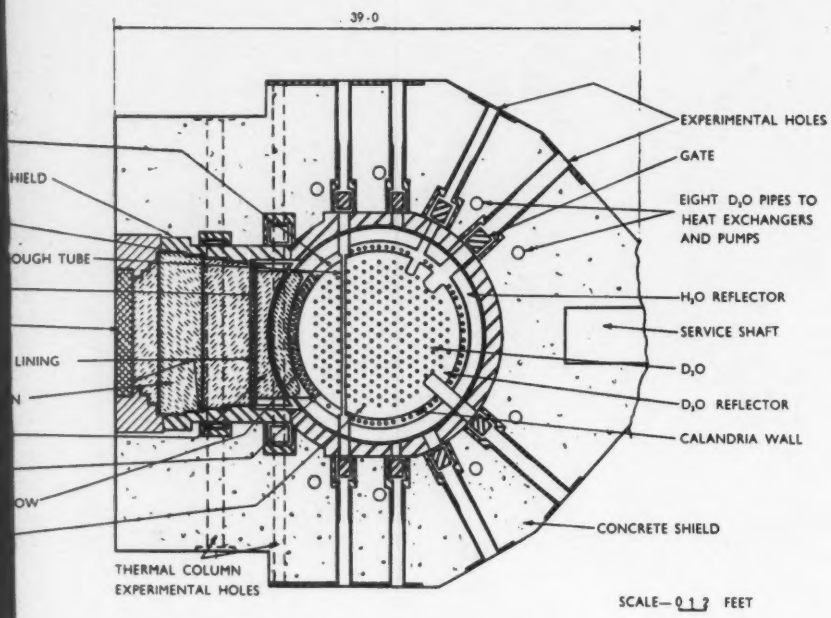
$B = 3.28\ m^{-2}$*

Escape Loss	
Temperature Correction	
Samarium Capture	
Xenon Capture	
Available Surplus	

*B is the geometrical buckling including effects of
control shut-off rods, the split in the lattice and
experimental beam holes.

Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. BEPO (April, 1956)
No. 2. CP5 (May, 1956)
No. 3. NRX (June, 1956)
No. 4. DIMPLE (August, 1956)
No. 5. ZEUS (September, 1956)
No. 6. CALDER HALL (October and December, 1956)
No. 7. RUSSIAN 5 MW (November, 1956)
No. 8. DIDO (January, 1957)
No. 9. THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION (February, 1957)
No. 10. BERKELEY POWER STATION (March, 1957)
No. 11. BRADWELL POWER STATION (April, 1957)
No. 12. DOUNREAY FAST REACTOR (June, 1957)
No. 13. EBWR (July, 1957)
No. 14. RWE 1 (September, 1957)
No. 15. LIDO (November, 1957)
No. 16. PLUTO (April, 1958)
No. 17. MERLIN (May, 1958)
No. 18. G1 (June, 1958)
No. 19 HINKLEY POINT POWER STATION (July, 1958)



orizontal facilities through the shielding some 12 in., some 6 in. meter. Beam holes provided with cooled gate just outside rmal shield.
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$B = 3.28$ m^{-2}*

e Loss	−0.085
erature Correction	−0.009
rium Capture	−0.006
n Capture	−0.029
	1.046
ble Surplus	0.046

the geometrical buckling including effects of vacant positions for ol shut-off rods, the split in the lattice and re-entrant cans for imental beam holes.

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The Physical Society's Exhibition

Many new exhibits of nuclear interest were on show at the 43rd Exhibition of Instruments and Apparatus arranged by the Physical Society and held at the Old and New Horticultural Halls, at Westminster, London, from January 19 to 22.

THE expansion of the Physical Society Exhibition in recent years poses more and more of a problem for the visitor with only a short time to spare. In the following review we have endeavoured to describe only those exhibits likely to interest people working in, or closely associated with, the nuclear engineering industry.

General Electric Co.

The use of heavy alloy for screening gamma radiation was featured by G.E.C. A 6-in. solid sphere weighing about 70 lb was shown as part of a remote handling set-up in an 8-in. lead brick wall. Equipment similar to that shown is being used at A.E.R.E. Harwell. Another G.E.C. exhibit showed the company's recently developed impermeable graphite under high-temperature conditions.

Ministry of Supply

Impermeable graphite could also be seen in a Ministry of Supply working exhibit demonstration, where the material was used as a tube for a high-temperature vacuum furnace. Following work at the Royal Aircraft Establishment, Farnborough, two methods of treating commercial graphite have been devised. One employs impregnation with furfuryl alcohol followed by polymerization and carbonizing in the pores; the other uses the pyrolysis of hydrocarbon vapours under conditions where the reaction probability is low, with the result that hydrocarbon molecules can diffuse deeply into the material before pyrolysis takes place. Permeability to air can be reduced by a factor of 10^6 without difficulty.

Fleming Radio

An automatic air pollution monitor on Fleming Radio's stand comprised a basic air-pollution recorder with a built-in unit for checking radioactivity in the sample. Samples can be taken at 1-hour, 8-hour or 24-hour intervals with a minimum time interval of 30 sec. The air to be assessed is drawn over a filter paper which is then transported to a sampling head with a three-position shielding arrangement, so that the various types of radiation can be separately analysed. The company have also developed a portable effluent monitor for testing any fluids suspected of being radioactively contaminated. The unit comprises a transistorized ratemeter and a beta/gamma counter tube with an encapsulated base, so that it can be completely immersed in the fluid to be tested.

(Right) The Mervyn-Harwell Square Wave Polarograph Mk. 3 has been re-designed to improve accessibility

(Below) 100-channel pulse spectrometer, type L.332 by Mullard Equipment.

Mullard Equipment

The 100-channel pulse spectrometer, type L.332, on Mullard's stand was based on an A.E.R.E. design. Design features include a continuous linear analogue display of the spectral curve on a 15 cm diameter cathode-ray tube, both during and after count period with precise read out from any channel on in-line numerical indicators. The short constant dead time of 250 microseconds, the high linearity and channel uniformity with no overlap or gaps between channels, together with the use of inter-Services approved components, make this instrument suitable for the most precise work even under tropical laboratory conditions.

Mervyn Instruments

The latest form of Mervyn-Harwell Square Wave Polarograph, the Mk. 3, was featured by Mervyn Instruments. All controls have been rearranged for greater convenience and adequate working space made available on the acid-resistant desk top of the console. A fully thermostatic cell holder is built in: it contains four Barker-type cells and twin dropping electrodes.

Burndept

A pocket geiger counter, model BN.118, was shown by Burndept. The unit is arranged to provide aural indication of gamma intensity, E.H.T. for the tube being derived from a single transistor oscillator. Other portable units on the stand included a transistorized gauge for measuring the thickness of galvanized plating and other coatings, together with a contamination monitor for detection of alpha, beta, gamma and neutron radiation.

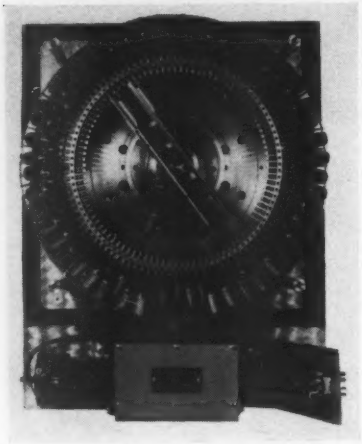
Engelhard Industries

The Baker Platinum Division of Engelhard Industries had several interesting nuclear exhibits. The Baker integral-sheath thermocouple, for example, has protection from thermal shock built in: the assembly comprises a flexible metallic outer sheath insulated from the centrally disposed thermoelements by means of a pure oxide refractory powder. For measuring the temperatures of nuclear fuel cans the company has developed demountable thermocouple assemblies, so that fuel elements can be changed without dismantling the associated circuitry. Engelhard also displayed their catalytic recombination equipment as used for recombining deuterium and oxygen emanating from the dissociation of the heavy water moderator in DIDO. This equipment was described in the January, 1959, issue of *Nuclear Engineering*.

J

Elliott Bros. (London)

A section of Elliott Bros.' large stand was devoted to mechanical engineering developments, one of the most interesting exhibits being a model of an automatic standpipe closure equipment for gas-cooled reactors. The device enables the lid of a standpipe to be remotely secured or removed whilst enclosed within a pressure-tight container attached to the standpipe body. When the lifting cap is raised, by a grapple operating within the pressure-tight container, it releases the toggle clamps and lifts the lid clear of the standpipe. On lowering the cap, the lid closes on to the standpipe and the toggle clamps are moved into position and locked.



The Elliott ND. 461 distance-velocity lag simulator comprises a 100-position motor driven switch.

On the instrument side, Elliotts were displaying a distance-velocity lag simulator, type ND.461, which has been specifically developed for simulating the delay in the movement of hot CO_2 in a reactor coolant circuit. The transport time provided by the instrument can be varied between 2 and 60 seconds. As this function is inversely proportional to the magnitude of an electrical input signal it can either be preselected to a constant value or caused to vary in relation to other plant parameters represented in, for example, an analogue computing equipment plotting the effect of large transit time delays.

Solus-Schall

A new dekatron-gated counter scaling unit featured by Solus-Schall is designed for operation with rate-meter/amplifiers so that the number of individual counts arriving in a pre-determined time is recorded or, more conveniently, the time for a certain number of counts is recorded. Whichever method is employed, an additional timing device must be mechanically or electrically coupled in such a way that the termination of counts stops the timer or vice-versa.

General Radiological

Designed as a general-purpose scaler for manual or automatic control, a fully transistorized equipment, the NE075 was featured by General Radiological. The count is displayed on transistor-driven dekatrons mounted in a well on the front panel. Parallax errors are avoided by mounting the illuminated numerals at the level of the dekatron cathodes. Another G.R. equipment, the NE042 is a precision timer for controlling banks of scalers such as those employed in foil counting.

S. Smith and Sons (England)

For research and development of miniature magnetic cores, S. Smith and Sons (England) have introduced a pulse-generating equipment comprising three identical generators. In each unit the pulse characteristics can be varied as follows: pulse altitude O-1A, pulse width 0.08-30 microsec, relative pulse delay 0.08-1000 microsec, pulse rise time 0.02-20 microsec. In addition the pulse repetition frequency of the master oscillator which drives the unit can be varied from 1 kc/s to 3 Mc/s.

Ericsson Telephones

Developed in conjunction with A.E.R.E., Harwell, the 126A vibrating reed electrometer displayed by Ericsson Telephones provides a means of measuring low voltages and small currents such as are encountered in ionization chambers. Other applications include the measurement of very high resistances, the determination of pH values, measurement of thickness by nucleonic means and mass spectrometry. The unit comprises a d.c./a.c. converter with three-stage negative feedback head amplifier and an indicator assembly with reed drive oscillator, phase discriminating detector, indicating meter and power pack.

A range of nucleonic equipment in unitized form and known as the 2,000 series has also been developed by Ericsson in conjunction with A.E.R.E., Harwell. The units are built on a standard dimensioned single- or double-width plug-in chassis, connection being effected via a rear-mounted McMurdo connector. Printed circuits are extensively used.

Baldwin Instruments

The latest developments in thickness gauging were to be seen on Baldwin Instrument's stand. The fast responding Atomat, for example, is intended for high-speed applications such as those encountered with metal-foil rolling mills. For a standard Atomat the maximum speed of response is 0.1 sec. By using a low capacity lead cable, however, the figure can be reduced to 0.04 sec. The gauging (and automatic rejection) of discrete sheets is thus possible even when the sheets are presented to the measuring head for a fraction of a second. Baldwin have also introduced an automatic standardization unit for existing Atomats.

Metropolitan-Vickers Electrical Co.

A model of the vacuum system for ZETA, specially built by Met-Vick for design study, was included amongst the company's exhibits. An ultra-high vacuum plant, the model is arranged to give differing combinations of pumps, baffles, tubulation and sealing arrangements. The pumping speed and surface area under vacuum are in scale with the actual equipment.

Edwards High Vacuum

The very large number of important new developments shown by Edwards High Vacuum provided a striking example of the present-day importance of vacuum technology. Edwards are now making mercury vapour pumps and liquid air traps in stainless steel for long life applications. The design has been modified to eliminate crevices and to reduce the number of gaskets.

A large chevron baffle has proved very effective where a high degree of freedom from pump oil vapour in the system being pumped is required. The baffle can be water cooled or refrigerated.

An ultra-high vacuum system on the stand demonstrated many special pieces of equipment, including a large s.s. shut-off valve which can be baked to a high temperature. The closed conductance of the valve is of the order of 10^{-9} litres/sec. At medium vacuum the valve will handle corrosive gases. Other interesting devices for ultra-high vacuum applications ranged from an ionization gauge (which can be baked to 450°C) for measuring pressures down to 10^{-11} mm Hg to demountable bakeable metal gasket seals capable of leak-free operation over a wide area of temperatures.

The GD1 Speedivac leak detector which was also on show is intended for the measurement of outward leakage from a pressurized system.

Self-standardizing Atomat beta thickness gauge with operator's remote control unit (Baldwin Instruments).

Damping constant meter, LDA2A by Cawkell Research and Electronics.

On the metallurgical equipment side, Edwards were showing the electron beam welding apparatus developed by J. A. Stohr of the C.E.A. at Saclay, France. Edwards are the British licensees for this unit which has been developed for capping fuel element cans where oxidation difficulties are encountered. The process is carried out in a vacuum of less than 10^{-4} mm Hg. The tungsten filament of the electron gun emits electrons which are accelerated to the work by a high voltage applied between the electron gun and the work which is at earth potential. The electron beam is electro-statically or magnetically focused; in this way high intensity localized heating can be obtained on the work-piece by the correct choice of electron spot diameter. The intensity of heating is controlled by alteration of the filament current and applied high tension.

Welding is carried out by moving the work (which is mounted on a turntable beneath the stationary electron gun) in respect to the focused beam of electrons. By this means welding diameters of up to 6 in. can be obtained. Varying work lengths are accommodated by utilizing the combined adjustments of the electron gun and turntable. Power for welding is supplied from a high tension control unit capable of delivering 20 kV at 100 mA: a variable pulsing unit is incorporated.

B.S.C.R.A.

On the stand of the Department of Scientific and Industrial Research, the British Steel Castings Research Association were showing a slide-rule calculator for the rapid calculation of exposure times in gamma radiography. The unit covers such variables as source strength, source speed and exposure time; it incorporates scales for use with cobalt-60, iridium-192, cæsium-137, thulium-170 and radon. Metric or inch scales are available.

Cawkell Research and Electronics

A portable unit for measuring the density of substances *in situ* was introduced by Cawkell Research and Electronics. A gamma source is used and the level of radiation is measured at a fixed distance away by means of a geiger counter. This level is inversely related to the density of the intervening material and curves are provided for the interpretation of results after allowing for the natural background of radiation. The instrument can also be arranged to measure the moisture content of the material. Cawkell also showed a new model of their damping constant meter, the LDA2A. Particular modifications provide for measurements at lower (50 c/s) and higher (up to 50 kc/s) frequencies.

Labgear

An automatic sample changer designed for the unattended assay of large numbers of radioactive samples offered for routine examination was shown in pre-prototype form by Labgear. The apparatus comprises three turntables; a heavily shielded detector head and associated drive and control circuits on a cast alloy base. Two of the turntables form turrets carrying columns in which the samples are stacked before and after examination. The third turntable transfers samples from the first turret to the detector, thence to the take-up turret. The sampling period is regulated by a programming unit and the output is evaluated and automatically recorded on a printing counter.

Ekco Electronics

Among the new reactor instruments introduced by Ekco Electronics there was an N638 log gamma monitor comprising an air-wall ionization chamber with amplifier head unit and a rack-mounted main amplifier connected together by up to 500 ft of cable. A true logarithmic range is provided from 1 milli-röntgen/h to 100 milli-röntgen/h.

The N596 beta/gamma survey meter is designed to meet the requirements of the impending Factory Act. Ranges of 0-3, 0-30 and 0-300 millirads/h are available, together with an integration facility up to 30 millirads. The new N600 ratemeter shown by Ekco incorporates a complete spectrum analysis facility in a discriminator unit which has an automatically or manually swept single channel.

Atomic Energy Authority

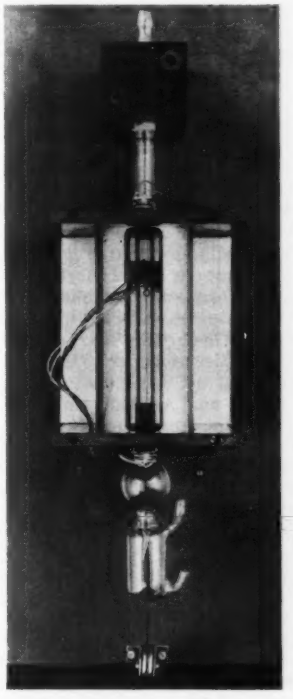
Four AEA establishments contributed to the Authority's exhibit this year. Aldermaston chose to show two types of automatic burette monitor with electronic register. Type A registers on a paper tape the height of liquid in a burette. A typical application is to record the end-point in a titration experiment. Type B automatically follows variations of liquid height and records them in the form of a graph. A.W.R.E. also showed a system of automatic magnetic field control intended for stabilizing electro-magnetic fields which are capable of being varied over wide ranges.

The Health Physics Division from A.E.R.E. featured personnel radiation monitoring by photographic emulsions. The four-section display showed (a) the organization of a typical film monitoring service; (b) a new nylon film holder; (c) progress in the development of film specifically for personnel monitoring; and (d) background information on dose levels and frequencies from official records.

A.E.R.E.'s Chemistry Division at Woolwich exhibited a differential cathode-ray polarograph. Finally, the Patents Exploitation Branch from AEA headquarters in London showed examples of their work in assisting British industry to exploit patents taken out by the Authority on a diverse range of techniques and equipment.

Barr and Stroud

An automatic scanner for locating nuclear particle tracks in photographic emulsion was to be seen on the Barr and Stroud stand. The unit is attached to a microscope. Light from the image of each small portion of the photographic plate traverses a number of slits and passes to a photomultiplier. The image is also rotated at slow speed so that the orientation of a particle track relative to the slit is changed for each successive slit. This ensures that, during the scan, one traverse is made with the particle track substantially parallel to the slit. When this occurs the photomultiplier receives less light and a signal is initiated.



Automatic burette monitor developed by A.W.R.E., Aldermaston, and shown on the AEA stand.

Twentieth Century Electronics

A new miniature high sensitivity photomultiplier tube with outstanding performance was displayed by Twentieth Century Electronics. The tube, BMS 10/14, is only ¾ in. diameter, yet it possesses a minimum overall sensitivity of 150 A/L with a maximum dark current of 0.1 μA.

This portable scintillation counter, type 1413A by Isotope Developments, can be operated from three torch cells.

Isotope Developments

Originally developed for geological prospecting, the 1413A scintillation counter featured by Isotope Developments has a high gamma sensitivity making it useful as an environmental survey meter. Completely portable, it can be operated from three torch cells. For pedestrian use earphones would normally be supplied: a suitable recorder and alarm unit is available for car-borne surveys.

Avo

For radiation measurement where it would be dangerous for an operator to expose himself directly, Avo introduced a remote indicator doserate meter. It consists of two parts, an ionization chamber and an indicating instrument which can be up to 15 ft away from the chamber.

The Avo hot spot monitor, shown in prototype form, is a very light portable battery-operated instrument with an ion chamber on an extending rod. The unit is intended for measuring radiation intensity in close proximity to high level sources of beta and gamma radiation.

Dynatron Radio

Two new prototype equipments were shown by Dynatron Radio. A nucleonic test set, comprising a double pulse generator and a d.c. coupled oscilloscope on a 12¼-in. by 19-in. panel, will assist users in checking their instruments. For use with BF_3 counters counting slow neutrons, Dynatron have also introduced a transistorized pulse amplifier and power supply.

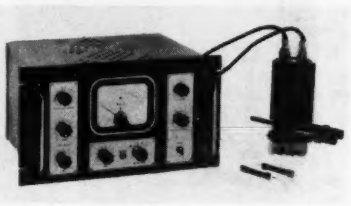
Sunvic Controls

A prototype of Sunvic Controls pulse height analyser, Mk. 3, was shown in console form. Largely transistorized, the instrument uses a ferrite core storage matrix which provides 100 channels, each with a capacity of 16 binary digits giving a decimal count of 65,535.

Kelvin and Hughes

The latest ultrasonic transducers developed and shown by Kelvin and Hughes for use with their flaw detectors operate as common transmitter/receivers. For immersion or contact testing techniques, they have frequencies of 1.5, 2.5, 5 and 10 Mc/s.

For use with a Mk. 5 ultrasonic flaw detector, a twin channel alarm unit automatically registers the presence of flaws providing the flaws occur within the duration of a "gate."



Vibron mass spectrometer amplifier (Electronic Instruments).

Electronic Instruments

Among the new instruments added to Electronic Instrument's range at the exhibition was a new Vibron mass spectrometer amplifier developed on behalf of the U.K.A.E.A. This fast response electrometer is intended for measuring short pulses of small currents. The high sensitivity and long-term stability have been achieved by incorporating a special 800 c/s Vibron unit.

SIR CLAUDE GIBB

An Appreciation

BY the death of Sir Claude Gibb, K.B.E., F.R.S., the nuclear industry loses a leading personality in every sense of the word; one whose efforts have done a great deal towards establishing Britain in the nuclear export field.

Claude Dixon Gibb was an Australian born in Queensland in 1898. He was educated at the South Australian School of Mines, and Adelaide University and served in the Australian Flying Corps.

In 1924 he came to England and joined C. A. Parsons and Co., Ltd., as a fitter, but his outstanding qualities were quickly recognized and by 1925 he had been appointed to special duties on the outside erection staff and was appointed Technical Director in 1929, General Manager in 1937 and Chairman and Managing Director in 1945.

During World War II he was appointed Director-General of Weapons and Instrument Production, and later Director-General of Armoured Fighting Vehicles and Chairman of the Tank Board. He was gazetted C.B.E. in 1942, knighted in 1945 and awarded the K.B.E. in 1956.

Sir Claude received his B.Eng. and M.Eng. degrees at Adelaide University, later being awarded the Angus Engineering Research Scholarship, the premier

Sir Claude Gibb.

Australian award. He was the recipient of honorary D.Sc. degrees from both London and Durham Universities and elected F.R.S. in 1946. For 22 years a Member of Council of the Institution of Mechanical Engineers, he was Vice-President for five years, but had to decline the Presidency owing to pressure of his other duties. He relinquished the chairmanship of A. Reyrolle and Co., Ltd., for the same reason.

In addition to his chairmanship of Parsons, he was also chairman of the Parolle Electrical Plant Co., Ltd., the Nuclear Power Plant Co., Ltd., and the Anglo Great Lakes Corporation, Ltd., employing between them some 20,000 men.

To introduce a personal note, although the present writer was not on any terms of intimacy with Sir Claude, he has been able on many occasions to get first-hand reactions of those around him. Meteoric as was his early career, there has never been any suggestion that his success was achieved at the expense of others—on the contrary, he commanded liking as well as respect amongst his staff. His unswerving devotion to duty on behalf of British industry, and his consequent disregard for his personal well-being have been responsible for his death at only 60 years of age. In offering our sympathy to Lady Gibb, we feel that her loss is shared by British industry as a whole.

The CERN nuclear research station at Meyrin, near Geneva, showing the 600-ft-diameter proton-synchrotron. In the background are the laboratories and management buildings.

World News

International

RESEARCH CONTRACT has been awarded by IAEA to the Physical Institute of the University of Trieste, Italy, as part of the Agency's programme of developing health and safety measures for the peaceful uses of nuclear energy.

Acting AEC chairman, Mr. H. S. Vance, presenting a letter of commitment to the Korean Ambassador in Washington, You Chan Yang, for the U.S.'s contribution of $350,000 towards the cost of a nuclear research reactor.

EURATOM, the European Atomic Energy Pool, has now come into full force, states an official communique issued from the headquarters at Brussels.

A COLLECTION of scientific periodical literature has been donated to the IAEA by the Academy of Sciences of the Soviet Union. The gift includes free subscriptions to 27 U.S.S.R. scientific periodicals.

ASSISTANCE in the form of equipment and technicians to Brazil, Pakistan and Thailand will be part of IAEA's technical assistance programme for 1959.

PRELIMINARY ASSISTANCE MISSION will be sent by IAEA to Burma, Thailand, Indonesia and Ceylon to survey conditions and possibilities for nuclear power.

LIBRARY comprising 19,000 micro-films has been presented to Euratom by the United States. Included in the collection are reference works such as the National Nuclear Energy Series and Nuclear Science Abstracts.

United Kingdom

NO AGREEMENT has yet been signed for the supply of an American reactor to power Britain's first nuclear submarine, "Dreadnought." The Admiralty recently disclosed that an American design of hull will now be used.

AN INFORMATION CENTRE, as part of the public relations branch, has been opened at AEA's London office. Its purpose is to provide a centre for members of the public, commercial companies and other organizations. Visitors will be able to see a wide range of unclassified material without security restrictions.

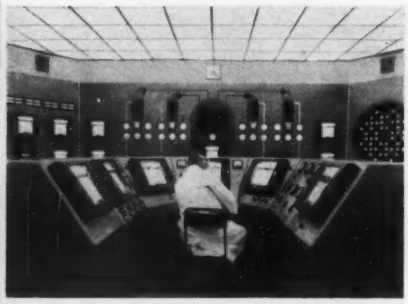
ARRANGEMENTS for marketing Aerojet General Nucleonics reactors in the U.K. are at present under way, and an agreement for the manufacture and sale of the reactors is likely to be signed soon with a British company.

Austria

THE FEDERAL MINISTRY of Education has purchased a new version of the TRIGA research reactor from General Dynamics of the U.S.A. It will be an above-ground model, Mk. 2 with neutron beam ports and thermal column in addition to the standard irradiation, isotope-production and training facilities.

Belgium

A CONTRACT for the sale of 10.049 kg of uranium enriched to 19.76% has been negotiated between the United States and the Belgian Government. The uranium will be used in the 10 kW TRIGA research reactor in the Belgian Congo.



Fluorescent lighting supplied by A.E.I. Lamp and Lighting, Ltd., in the Chapelcross control rooms. Above: One of the reactor control rooms using a luminous ceiling. Left: Turbine control room with Perspex laylight for main lighting and vertical illumination of control panels provided by angled reflectors around the laylight.

Canada

ACCORDING to Eldorado Mining, the Government's uranium purchasing agent, deliveries of uranium concentrates in the first nine months of 1958, totalling 9,338 tons, were more than double the tonnage delivered for the same period in 1957. At the same time the value rose from $90.96 to $192.9 million.

ABOUT 3,000 TONS of uranium ore is being handled daily by Milliken Lake Uranium (a member of the Rio Tinto group).

TWENTY-TWO URANIUM producers have urged the Government to take steps to ensure stable markets after the expiration of present contracts in 1962 and 1963.

El Salvador

AN ATOMIC ENERGY COMMISSION has been formed to study the possible uses of nuclear power for the country.

India

THE ATOMIC ENERGY COMMISSION have proposed the installation of about 1,000 MW of nuclear power by the end of the third five year plan (March, 1966). The Government have decided that a minimum of 250 MW of nuclear power is to be included in the power programme and it is intended to have the first nuclear power-plant ready by mid-1964.

Japan

VICE-PRESIDENT of Japan's Atomic Power Generation Co., Mr. Tamaki Ipponmatsu, has stated that he hopes construction of a site for a Calder Hall type powerplant will be started in Eastern Japan this summer. Tender prices were first examined in the middle of January and cost studies are expected to take three weeks. Letters of intent should be issued some time in March.

THE GOVERNMENT is to purchase 3,000 kg of natural uranium in ingot form from IAEA at $35.50/kg.

Netherlands

THIN LAYERS of soil bearing uranium have been discovered at a depth of 100 to 125 ft in the province of Overijssel.

New Zealand

PROSPECTING WORK on their uranium-bearing holding in the Bullock Creek area on South Island's west coast, will be carried out by Brighton Uranium Prospecting. It is believed that large quantities of uranium exist in the area and the New Zealand Mines Department is co-operating with the company in the initial investigations.

The Prime Minister beside one of the Bradwell heat exchangers during his visit to the Head Wrightson works at Stockton-on-Tees.

Puerto Rico

A CONTRACT for a design study for a boiling water nuclear powerplant, incorporating a nuclear superheater to increase steam temperatures, has been placed with the U.S. AEC by the Puerto Rico Water Resources Authority.

Rumania

NEW LABORATORY for cosmic ray research has been made available at the Atomic Physics Institute of the Academy of the Rumanian People's Republic.

South Africa

TOTAL OUTPUT of uranium oxide during 1958 amounted to nearly one-fifth of world production. In all 7,000 tons were produced in the Union. This year's exports were valued at £50 million.

URANIUM OXIDE at the price of £3 8s. per pound, has been offered to the IAEA in response to the call for tenders for supply of uranium.

Thailand

PLANS for a 20 to 40 MW nuclear power station are under consideration.

A stage in the intensive corrosion studies on fuel element materials being conducted by G.E. at Hanford.

West Germany

UNIVERSITY OF FRANKFURT'S research reactor has reached its full design power of 50 KW. The reactor is a solution type using enriched uranium in a water solution as fuel.

U.S.S.R.

ALL THREE REACTORS have now been installed in *Lenin*, the nuclear ice-breaker. Tests of engine-room equipment have been under way for some months and only interior fittings and furnishings of the vessel need to be completed.

AN ATOMS FOR PEACE exhibition was held recently at the Chinese-Soviet Friendship Palace in Shanghai. Illustrating the application of nuclear energy in Soviet industry and agriculture, the display included a model of *Lenin*, the nuclear-powered ice-breaker.

U.S.A.

CECIL KELLEY, a technician at the Los Alamos scientific laboratory, died recently as a result of radiation burns. He was exposed to about 1,000 Röentgens. Kelley was engaged in an operation in the recovery of plutonium from a waste solution.

OIL AND CHEMICAL technicians met in Dallas recently to discuss the possibility of using nuclear explosions to recover millions of gallons of oil in Colorado, Utah and Wyoming.

NINE PROPOSALS from industry to design, develop and build a factory-assembled, modular nuclear power plant, have been received by the AEC. The new plant will incorporate advanced technology to provide factory-assembled modules or units which can be air-transported to remote sites and rapidly assembled. The modular concept will also enable the plant to be disassembled and relocated.

A NEW PROGRAMME of assistance to colleges and universities for education and training in radioisotopes principles and technology, is to be launched by the AEC. The programme will allow for direct financial assistance in obtaining equipment.

SPECIAL POWER EXCURSION Reactor Test No. 3 (SPERT-3), situated at the National Reactor Testing Station, Idaho Falls, achieved criticality recently. The reactor has been built for studying nuclear reactor safety.

AN ORDER affirming and amending a construction permit for a fast breeder reactor, has been issued to PRDC by the AEC. The order continues the existing permit with modifications and additions.

SUNDANCE, WYOMING, has been selected by the USA Air Force as the site for the installation, and test operation, of a factory-assembled modular nuclear power plant for use in remote military installations. The plant will be a pressurized water reactor, cooled and moderated by light water using enriched uranium as fuel.

A TRAINING PROGRAMME has been established at Shippingport nuclear power station for supervisory personnel of domestic and foreign organizations engaged in or planning the design, construction or operation of nuclear power plants.

A REVISION SHEET SERVICE has recently been inaugurated by the AEC to keep the Trilinear Chart of Nuclides up to date. The service, which is in the form of stick-on amendments, is available on an indefinite subscription basis at $1.00 ($1.25 outside the U.S.) from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

BASIC CHARGES for uranium 233 and plutonium for use in research and development to private individuals and companies in the United States and foreign governments, have been established. The charges are $15 per gram for uranium 233 and $12 per gram for plutonium. In the U.S., material of this nature may be owned by the government only, but may be leased to industry. Nuclear materials can also be either sold or leased to foreign governments having agreements with the U.S.

A view from above of the 95-ton pressure vessel for the Westinghouse testing reactor under construction at Waltz Mill. Built by Pacific Coast Engineering, it is 33 feet high and has an inside diameter of 94 inches.

THERMO-ELECTRIC GENERATOR, developed for the AEC by the Martin Co. and the Minnesota Mining and Mfg. Co., is said to be capable of 5 W output with a weight of only 3 lb. The original model is fuelled with polonium-210 (half life 138 days).

PROPOSALS for three new reactor concepts have been accepted by the AEC. Contracts are being negotiated. The proposals are by American Radiator and Standard Sanitary for a mercury-cooled, fast breeder reactor; General Electric for a modified sodium graphite reactor with modules containing fuel and coolant, and Babcock and Wilcox for a gas suspension coolant reactor.

THE DESIGN, construction and operation of a gamma irradiator for investigations into industrial applications of high-level radiation, will be sought by the AEC from private industry.

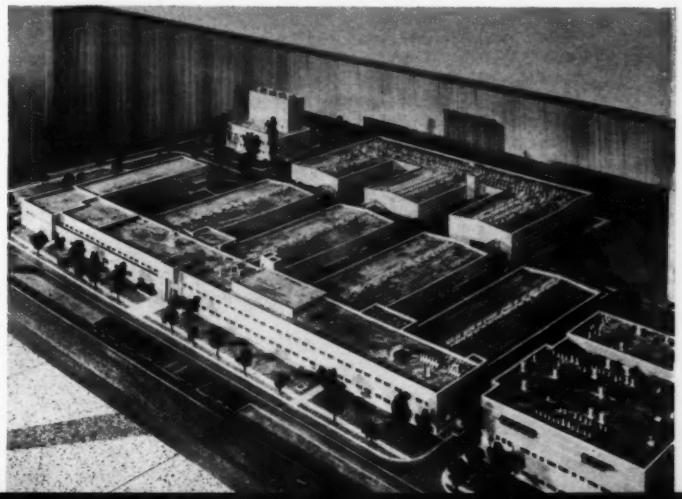
EIGHT PROPOSALS for the research and design of a fast breeder reactor, using a plutonium oxide-uranium oxide fuel cycle, have been received by the AEC. The objective is to lower the cost of electric power from fast breeder reactor power stations by reducing fuel cycle costs.

ANOTHER NUCLEAR-POWERED submarine, the " U.S.S. Halibut," has been launched by the Navy. It will be the first capable of firing guided missiles.

OAK RIDGE National Laboratory have received a request from AEC's Division of Research to investigate the design and construction of an ultra-high flux reactor.

SCIENTISTS from the Argonne National Laboratory Division of Biological and Medical Research have discovered two compounds that successfully remove plutonium from the bodies of rats—even after treatment has been delayed for a few days. The two compounds will be known as DTPA and BAETA.

A DEMONSTRATION took place in New York recently of an inexpensive device which it is claimed, will give effective and timely warning of the presence of dangerous concentrations of radioactive fall-out. Built by Tracerlab, the device can be plugged into any radio or television set. Alarm is given in the form of a wailing device which increases pitch as radioactivity increases.



Model of the planned extension at the Oak Ridge National Laboratory main research building, Tennessee, U.S.A.

Orbits in Industry

THERE is a story, which has been told so often that its origin is now attributed to A. Pocryphal et Al. (Never forget Al, he writes a lot of good stuff, like Anon. and Tradit.) It concerns a bunch of mathematicians who proved, beyond all doubt, that the bumble-bee had the wrong aerodynamic shape, too much drag, and such a poor power-weight ratio that it could never get off the ground. Unfortunately, nobody has ever managed to communicate the results to the bee, so that, unaware of his frightful handicap, the poor ignorant clot just keeps on flying. Whether or not this is true, Tangent was irresistibly reminded of it on a recent visit to Norway when, visiting the Kjeller establishment, he was introduced to JEEP and heard some of its history.

Now JEEP almost qualifies for founder membership of the Reactor Club. It is not as old as BEPO or CP3 or ZOE, but it did go critical in 1951, which is no small achievement in itself. At that time anything to do with nuclear matters was so secret that, had this journal existed, it would have been hard-put to replace the members of its staff who had either been shot out of hand, or were languishing in the cold stone jug under regulation 18B. Not only were secrets kept from the common herd, they were also kept from fellow-workers, so that when the would-be designers of JEEP were trying to obtain information, their reception both in the U.S. and the U.K. was sufficiently unfruitful to make most men give up.

Those who saw (as Tangent did) Norwegians arriving in 1940, having crossed the North Sea in open boats propelled by ancient diesels practically running on melted bacon-rinds, will, however, realize that they are not an easy race to discourage. (Neither, for that matter, are the Dutch—joint owners of the reactor—noted for scaring easily.) Emulating the bumble-bee, they just got down to building a reactor and JEEP is the result. It is not a powerful unit—half a megawatt—and it has the beautiful simplicity of a "Model T." It has an aluminium tank, 3 mm thick, and it operated for five years without any treatment plant for the heavy water. (This alone would make the reactor designer of today scream the place down.) It has control and shut-down plates suspended by bicycle chains.

Yet it has, according to the latest available figures, clocked up 420 MWd and is still going strong, a monument to the principle of "let's have a bash at it, anyway," and a testimonial to what can be achieved by men with very little money or man-power—with, in fact, very little anything, except a great deal of strength of purpose and a considerable faith in their own capabilities. More power to their elbows!—and may the Norwegian licensing laws be relaxed, so that they can lift them more often.

DR. FINAGLE'S LAWS—8

Law of Beams (2)

Any beam carrying plant loads will, on completion, be required to carry, in addition, the equivalent of the total "project" loading applied as a central point load.

Corollary I

All calculated reactions will be 25% too low.

Corollary II

Estimated reactions might conceivably be correct.

Readers of the *Unclear Times* which, in spite of editorial vigilance, manages to creep into these chaste pages each December, may remember the account of Dr. Finagle's work with the bread-and-butter launching machine, to demonstrate that, according to the Law of Maximum Inconvenience, the majority landed buttered side downwards. The account has, however, raised some correspondence from Tangent's Regular Reader, who points out that Finagle is by no means alone in this field. He says:—

> . . . Research in this country started in earnest with the construction of BEPO (Bread Experimental Projecting Outrage) and, since then, has tended to concentrate more and more on the results of spreading jams and other more exotic confections on the bread. We are not alone in this, of course. The Americans have OMRE (Orange Marmalade Research Engine), ALPR (Argonne Liver Paté Rig) and EBWR (Experimental Bread and Waffle Random launcher) to name only a few. The Russians are producing remarkable results with ALPHA (Apple, Loganberry and Plum-jam Heaving Assembly) and OGRA ('Orizontal Gyrating Raspberry-jam Apparatus). This latter is believed to have originated in China, where the horizontal model is traditional. To maintain our world lead in this field, we are at present working on HTGC (Honey, Treacle and Guava-jam Chucker). . . .

The response to our original appeal for early manuscripts of Dr. Finagle's works has proved disappointing. Will anyone possessing any Laws which have not yet appeared, please forward them so that the series may not come to an end? Payment will not be made, but contributors' names will be withheld, as part of the service.

Five-Six-Special?

According to Press reports, Tracerlab Inc. have produced a gadget which can be plugged into a radio or TV set causing a loud wailing noise in the presence of radioactivity. It is only fair to record, however, that the B.B.C. have had for many years a gadget which makes loud wailing noises in radio sets. It is called a "microphone."

Pictures in the Snow

Engineers, as everybody knows, cannot carry on any sort of conversation without sketching on tablecloths, napkins, paper towels, or, in emergency, on shirt-fronts. Until his Norway trip, however, Tangent had never seen enthusiasm so fierce that senior members of the Institutt for Atomenergi, just getting out of a car to enter a cafeteria at lunch time, could not wait to get out of the weather (2°F). Instead, they squatted down on the pavement and sketched rapidly in the snow, occasionally doing a little snow-sculpture when two-dimensional representation was found inadequate.

This conduct caused a certain amount of curiosity in such of the local inhabitants as had braved the weather, until Tangent, who was rapidly turning into an Abominable Snowman, ventured to suggest a move inside. At the sound of English, the inhabitants merely shrugged and passed on—what else could one expect? Since it was just before Christmas, it would, perhaps, be permissible to set some new words to the tune of "Good King Wenceslaus":—

> Tangent's eyeballs near popped out
> In the streets of Halden
> Damply blew the snow about
> (Damp and blooming *kaldt*-en!)
> When he saw, to his dismay
> (More than words can utter)
> Backroom boys from I.F.A.
> Drawing in the gutter.
>
> "Gentlemen," he said, "I'm blue
> This could not be drearier;
> Might we not proceed into
> Yonder cafeteria?
> Over sandwiches and beers
> You will still be able
> To—as do all engineers—
> Scribble on the table."
>
> Off the Halden people walked,
> Knowing that, of course, men
> Talking like this stranger talked
> Couldn't be true Norsemen;
> "They are Englishmen abroad"
> One was heard to mutter
> "And—as we are well assured—
> They are *always* Nøtter*."

*Nuts, to you.

Tangent

Personal

Mr. C. Dotson

Dr. R. A. Charpie

Mr. J. W. Laing

Mr. T. H. Kelsey

Appointments

Mr. W. Strath, formerly of AEA, member for overseas and industry, as permanent secretary to the Ministry of Supply.

Maj.-Gen. A. R. Luedecke, as general manager and **Mr. P. F. Foster** as deputy general manager of AEC.

Mr. G. N. Blades as regional manager (London), British Insulated Callender's Cables. His position as divisional sales manager (rubber cables) at the Leigh Works will be filled by **Mr. D. I. S. Hinton.**

Mr. R. A. Charpie as director, reactor projects division, to replace **Mr. W. H. Jordan,** who has been made assistant director of Oak Ridge National Laboratory (operated by Union Carbide Corporation).

Dr. R. Ringo as associate director, physics division of the Argonne National Laboratory.

Mr. S. J. Woolridge to the board of Metal Sales.

Mr. C. D. Boadle as technical manager of the atomic energy division of Teddington Aircraft Controls.

Mr. G. C. Fairbanks and **Mr. M. V. Needham** to the board of Elliott Nucleonics.

Sir William Scott and **Sir Richard Bellingham Graham** to the board of Head Wrightson Teesdale.

Mr. P. Holton as manager of the photomultiplier applications advisory service of 20th Century Electronics.

Mr. S. A. Ghalib, general manager; **Mr. J. R. M. Southwood,** chief engineer; **Mr. B. M. Bonfield,** secretary, and **Mr. A. R. Laing,** assistant secretary of A.E.I.-John Thompson Nuclear Energy Group.

Dr. R. Ringo

Mr. P. Holton

Sir Percival Liesching to the board of Automatic Telephone and Electric.

Mr. L. E. Eldridge to the board of British Thermostat.

Mr. H. W. Wagner as chairman of Sturtevant Engineering.

Mr. R. Craig Wood to the board of Associated Electrical Industries.

Mr. J. Jack financial director of Dorman Long and Co. and Dorman Long (Steel), **Mr. E. T. Judge** assistant managing director of Dorman Long (Steel).

Mr. S. Adams as chairman of Bakelite. He succeeds **Mr. H. V. Potter** who has retired but continues as a director.

Mr. L. Drucquer as chairman of A.E.I. divisional management and division director and general manager of the A.E.I. Heavy Plant Division.

Mr. A. Broomhead as assistant managing director of Thos. Firth and John Brown.

Mr. T. H. Kelsey, assistant general manager and **Mr. J. W. Laing** chief engineer of Witton Engineering Works. This follows the integration of Witton and Erith Works into a single engineering group under the control of **Mr. A. L. G. Lindley,** assistant managing director of General Electric.

As officers of the Gauge and Tool Makers' Association for 1959: **Sir Stanley J. Harley,** president; **Mr. A. L. Dennison, Mr. H. S. Holden, Mr. T. Ratcliffe, Mr. L. E. Van Moppes,** vice-presidents; **Mr. G. P. Barrott,** chairman; **Mr. R. Kirchner, Mr. H. G. Carmichael Wilson,** vice-chairmen; **Mr. J. C. Brown,** hon. treasurer.

Mr. N. J. Chanter as manager of the transmitting and microwave division of Mullard Radio Valve.

Mr. F. L. Gibson as home sales manager of Wolf Electric Tools.

Mr. C. Dotson as chairman of the board of Texas Instruments.

Mr. C. R. Wills as general manager of Acheson Colloids, Plymouth.

(*Continued on page* 88)

NEW YEAR HONOURS

KNIGHTS

Mr. A. F. Burke, deputy chairman and managing director, de Havilland Aircraft; **Maj.-Gen. C. A. L. Dunphie,** managing director, Vickers; **Mr. J. W. Laing,** president John Laing and Son; **Mr. P. R. Linstead,** Rector, Imperial College of Science and Technology; **Mr. E. J. Pode,** managing director, Steel Company of Wales; **Mr. K. T. Spencer,** chief scientist, Ministry of Power.

C.B.E.

Mr. S. E. Clotworthy, managing director, North Aluminium Co.; **Mr. M. Cook,** chairman, Metals Division, I.C.I.; **Mr. P. T. Fletcher,** deputy managing director industrial group headquarters, Risley, AEA; **Mr. L. T. Morton,** joint managing director, Clarke Chapman; **Mr. J. H. Reed,** managing director, Ericsson Telephones; **Mr. J. McW. Storey,** managing director, Dewrance and Co.

O.B.E.

Mr. T. Bancroft, production and works director, Blackburn and General Aircraft.

Mr. P. Mummery, senior principal scientist, Reactor Division, AEA, Harwell.

Mr. F. S. Dennard

Mr. I. H. Hogg

M.B.E.

Mr. I. H. Hogg, senior resident planning officer, Research and Development branch, industrial group headquarters, Risley, AEA; **Mr. D. Sleath,** chief draughtsman inst. dept., Laurence Scott and Electromotors.

Mr. S. H. C. Bell, charge hand, research A.W.R.E., Aldermaston.

British Empire Medal, Civil div.

Mr. S. H. C. Bell, charge hand, research and experimental mech., A.W.R.E., Aldermaston.

Mr. R. J. Green as publicity officer of Technograph Electronic Products.

Mr. D. G. Ashton-Davies as sales manager of the instrument division of E.M.I. Electronics, and **Mr. C. Kramskoy** as chief engineer, commercial division.

Mr. S. F. Steward as director-designate of British Electrical and Allied Manufacturers' Association.

Mr. K. A. Robinson as chief engineer, and **Mr. W. F. Hill** as chief development engineer of the Lancashire Dynamo Electronic Products.

Mr. W. Warren as chief generation engineer (East Midlands Division), and **Mr. E. Forth** as chief generation engineer (North Eastern Division) of the Central Electricity Generating Board.

Dr. M. Davis and **Mr. J. M. Hutcheon** as deputy heads of AEA's research and development laboratories at Culcheth.

Mr. E. B. Banks as director of commercial policy, contracts and sales; **Mr. P. L. de Laszlo** as director of corporate affairs; **Mr. W. M. Hurton** as director of group manufacturing development, and **Mr. L. H. Short** as director of overseas operations of English Electric.

Dr. Paul Ruegger of Switzerland as chairman of an IAEA panel to consider problems of third party liability in nuclear energy.

Mr. R. J. W. Rudkin and **Mr. A. L. White** have been appointed additional directors of Vickers-Armstrongs (Shipbuilders).

Mr. H. Woodward to the board of Vitro Corporation of America.

Mr. D. C. Lorkin as managing director of Lancashire Dynamo.

Mr. P. Fuller as manager, components division, Dewhurst and Partners.

Mr. F. B. Lee as assistant sales manager, accumulator dept. of Siemens Edison Swan.

Mr. G. C. C. Miller as sales engineer (North) of Wayne Kerr Laboratories.

Mr. C. Watson, sales director of British Ermeto.

In the new cables division of Siemens Edison Swan, **Mr. D. E. Beavan,** home cable sales manager; **Mr. R. G. Holland,** export cable sales manager; **Mr. D. G. Skinner,** telephone cable sales manager; **Mr. H. S. Peet,** distribution equipment sales manager: **Mr. J. A. C. Kendle,** wiring accessories sales manager; **Mr. J. C. E. Coomber,** contract sales manager; **Mr. R. B. Tucker,** assistant home cable sales manager: **Mr. H. E. Helwig,** associations liaison officer: **Mr. P. W. Kilroy,** special projects sales manager.

Retirements

Mr. J. Horridge, works manager of George Kent.

Mr. E. A. Sayers, regional manager (London) of British Insulated Callender's Cables.

Mr. F. Fennemore, district representative (Midlands and South West) of Bryan Donkin.

Mr. W. Hunt, general works manager of Ferranti.

Obituary

Nuclear Engineering records with regret the deaths of the following personalities:—

Sir Claude Gibb, chairman and managing director of C. A. Parsons and chairman of the Nuclear Power Plant Co., Anglo Great Lakes Corporation and Parolle Electrical Plant, at the age of 60. (An appreciation of Sir Claude appears on page 82.)

Mr. W. Elkington Wright, director of Pyrene, on December 11, after nearly 30 years with the company.

Professor W. Pauli, Nobel Prize Winner for Physics (1945) in Zürich, on December 15 at the age of 58.

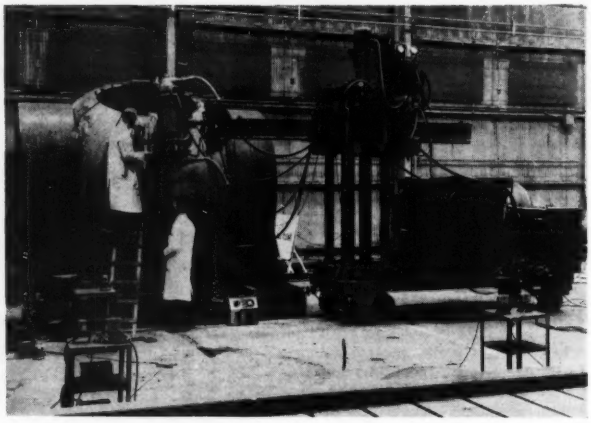
Mr. J. S. Fleuret, sales director of Northey Rotary Compressors, on January 4, at the age of 39.

Dr. H. Sulzer, president of Sulzer Brothers, Winterthur, Switzerland, on January 3, at the age of 82.

Tours

Mr. H. M. Drake, chairman and managing director of Drake and Gorham to South Africa to examine the possibilities for electrical contracting and switchgear.

Industrial Notes



An automatically-welded 2¾-in. thick stainless steel sphere under radiographic examination by a 400 kV X-ray generator in the South Works (Stockton-on-Tees) of Ashmore, Benson, Pease and Co. On completion the sphere will be tested to 2,550 p.s.i.

Stewarts and Lloyds' new 48-in. heavy steel rolling mill at Corby, Northamptonshire, was brought into operation only 10 days after the 42-in. mill, which it displaced, was closed.

General Electric have reached an agreement with **Vacuum Industrial Applications** for the development of vacuum heating techniques and the design and manufacture of complete vacuum furnace installations.

I.C.I. (Belgium) S.A., agents for **Marston Excelsior** of Wolverhampton, have obtained an order worth over £100,000 for aluminium piping for the experimental water-cooled reactor, BR.2, now being built at the nuclear research centre at Mol for **Centre d'Etudes Nucleaires.** Both companies are subsidiaries of **I.C.I.** This is believed to be the first large order, related to nuclear energy, to be obtained by a British firm in Belgium. The order comprises piping and fittings in aluminium alloy up to 30 in. diameter for the reactor coolant circuit.

James Gordon Valves has been formed to take over the valve activities of **James Gordon and Co.** Headquarters will be at Airport Works, Rochester.

Two courses at the Harwell Reactor School have been announced. The first is for senior technical executives from June 15 to 25 and the second is on control and instrumentation of reactors, from July 7 to 17.

Nuclear power developments in the Argentine and Peru will be discussed at a meeting in the Main Conference Room, Board of Trade, Horse Guards Avenue, London, on January 28 (3 p.m.). Speakers will include Mr. C. J. T. Spearman, First Secretary (Commercial) to the British Embassy in Rio de Janeiro, and Mr. K. D. Jamieson, First Secretary (Commercial) to the British Embassy in Lima.

G. and J. Weir, have changed their name to **G. and J. Weir Holdings.** Cathcart trading undertaking will now become G. and J. Weir as a subsidiary company.

Aerojet General and **Westinghouse** have signed an agreement for the distribution of AGN's reactors throughout the world. This agreement excludes the United States, where Aerojet handle their own sales work, and the United Kingdom.

Plessey have concluded an agreement with **Arnold Engineering,** of Illinois, for the interchange of technical information concerning the manufacture of cast permanent magnets of high energy for use in the electronic and electrical industries.

The **Department of Scientific and Industrial Research** will double its expenditure on research during its next five-year period. This means that approximately £61 million will be made available as compared with £36 million during the past period. The Department will also take over part of the former Royal Ordnance Factory at Thorp Arch, Yorkshire, for the new National Lending Library for Science and Technology. The library is expected to become operational in 1961.

West's Piling and Construction have opened offices at 42 Triangle West, Clifton, Bristol. Tel. Bristol 26906.

Bristol Aeroplane and **Rolls-Royce** have sold their interests in **Rotol** and the company is now a wholly-owned subsidiary of the **Dowty Group.**

Gear-O-Matic Division of Michigan Tool, Detroit, have developed a high-capacity demand-feed storage unit for pipe fittings or any similar parts that can be rolled. It has been designed for use in automatic processing lines.

Ellay Tubes have opened a new factory at Maidenhead.

Birlec have transferred their South Eastern area office to Crown House, Aldwych, London, W.C.2. Tel. Temple Bar 8040.

Elliott Nucleonics will assume all responsibility for activities in the nuclear field of Elliott Bros. The company will carry out instrumentation and control work on the four civil nuclear power stations and the design and manufacture of control-rod mechanisms for the advanced gas-cooled reactor which is being built at Windscale.

The AEA are applying for associate membership of the Engineering Equipment Users Association for a period of two years.

Texas Instruments have announced the third substantial price reduction within 12 months. In some cases this is as much as 35%.

Electrical Remote Control will hold an exhibition of electrical timing and automatic control equipment at the Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham, 2, on February 10 and 11.

Bradford Institute of Technology are to hold a course of lectures on nuclear reactor technology beginning April 20 and ending May 30.

Ferranti have installed a Mercury computer at AEA's Industrial Group Headquarters at Risley. Later this year a PACE computer supplied by Electronic Associates, will also be installed at Risley.

The Power Plant division of **Elliott Bros. (London)** has been amalgamated with **James Gordon** in order to offer schemes for complete instrumentation and control for nuclear and thermal power stations, process steam plants, heating, ventilating and air-conditioning plants.

Expansion joints.—On page 28 of the January issue we incorrectly reported that the bellows units being designed by B.T.H. (and having a working pressure of 250 p.s.i.) were intended for Berkeley. The working pressure at Berkeley is, of course, 125 p.s.i.

Electrama will stage a general exhibition of the French electrical engineering industry and of the applications of electricity in modern life from June 12 to 28 at the Centre National des Industries et des Techniques Paris. Organizer's address is M. le Commissaire Général, Electrama, 14 Rue de Magdebourg, Paris 16.

The Milan International Samples Fair for 1959, to be held from April 12 to 27 will include a new pavilion devoted to nuclear energy for peaceful purposes.

An impressive night photograph of Babcock House, Euston Road, London, showing the new illuminated clock. Twelve feet in diameter, the clock is 110 feet above street level.

Leeds and Northrup, of Philadelphia, have received a contract valued at £225,000 from the Argonne National Laboratory for the complete instrumentation and control systems for the experimental breeder reactor No. 2 (EBR-2), now under construction at the National Reactor Testing Station.

The Index for the 1958 volume of *Nuclear Engineering* is included as an insert in this issue. Because it is not stitched in, it has been necessary to reduce the size of the page, but a limited number of uncut copies are available for those wishing to include them in bound copies.

The Mechanical Engineering Laboratories at Robert Gordon's Technical College, Aberdeen, are to carry out a research project on heat transfer. It will be sponsored by the AEA.

Teddington Aircraft Controls of Merthyr Tydfil, have formed an atomic energy division.

Meetings

January 30 — Women's Engineering Society, London Branch, Hope House, 45 Great Peter Street, Westminster, London, S.W.1. "Some Uses of Electron Beams in Metallurgy," Mrs. I. H. Hardwich, M.A., A.M.I.E.E., A.Inst.P., at 7 p.m.

February 2—Institution of Electrical Engineers (Chester Town Hall at 6.30 p.m.). "Electrification of the U.K.A.E.A. Industrial Group Factories," J. W. Binns and W. J. Outram.

February 3—Institution of Chemical Engineers (joint meeting of North Western Branch with Graduates and Students Centres in the Chemical Engineering Building, Manchester College of Science and Technology, Jackson Street, Manchester). "Effluent Disposal and Air Pollution."

February 4—British Nuclear Energy Conference (sponsored by the Institute of Fuel at The Institution of Civil Engineers, 1-7 Great George Street, London, S.W.1, at 5.30 p.m.). "A Radio-active Corrosion Probe," D. Anson.

February 5—Institute of Fuel (Liverpool Engineering Society's Rooms, 9 The Temple, Dale Street, Liverpool, at 7 p.m.). "Statutory Requirements of Steam and Pressure Vessels," W. A. Mills.

February 9—Institution of Electrical Engineers (Assembly House, Norwich, 7.30 p.m.). "Operational Experience at Calder Hall," K. L. Stretch.

February 10—Society of Chemical Industry (Chemical Eng. Group) (14 Belgrave Sq., S.W.1, 6 p.m.). "The Extraction of Thorium," W. D. Jamrack, R. A. Wells and Dr. J. H. Buddery.

February 11—Institute of Fuel (Engineers' Club, Albert Square, Manchester, 2, at 2.30 p.m.). "The Operation of Calder Hall," J. Gawthrop.

February 12—The Institution of Chemical Engineers (The Hoare Memorial Hall, Church House, Great Smith Street, S.W.1, 9.30 a.m.). Symposium on mass transfer.

February 12—Institution of Electrical Engineers (S.W.E.B. Showrooms, New George Street, Plymouth, 3 p.m.). "Nuclear Power Generation," W. J. Prior.

February 16—Institution of Electrical Engineers (Royal Institution, Colquitt Street, Liverpool, at 6.30 p.m.). "Thermonuclear Processes," D. W. Fry.

February 17—Institution of Electrical Engineers (C.E.G.B., 1 Whitehall Road, Leeds, 1). "Electrical Installation at Calder Hall Nuclear Power Station," N. J. Mackay and E. Hardwick.

February 18—Institution of Electrical Engineers (Grand Hotel, Sheffield, at 6.30 p.m.). "Electrification of the U.K.A.E.A. Industrial Group Factories," J. W. Binns and W. J. Outram.

February 19—Institute of Metals (College of Technology, Gosta Green, Birmingham). "Materials for Reactors," B. C. Woodfine.

February 20—Institute of Marine Engineers (South Wales Institute of Engineers, Park Place, Cardiff, at 7 p.m.). "Nuclear Steam Propulsion for Merchant Ships," W. R. Wootton.

February 23—Institution of Electrical Engineers (Engineers Club, 17 Albert Square, Manchester, 6.15 p.m.). "Operational Experience at Calder Hall," K. L. Stretch.

February 26—Institution of Electrical Engineers (Liverpool Philharmonic Hall, 6.45 p.m.). Faraday Lecture "Automation," H. A. Thomas.

Catalogues

The fifth edition of **Acheson Colloids** newspaper-format publication, *Prospects*, features several articles on the applications of the firm's products for nuclear energy. (70 Hill St., Richmond, Surrey.)

Tracerlab have featured their new SC-47A tracer-scanner in the current edition of *Tracerlog*. (1601 Trapelo Road, Waltham 54, Mass., U.S.A.)

The Electricity Council have published a booklet called "Power for the Future," outlining the developments of electricity supply in the past and giving an estimate of the rise in demand over the past few years together with an indication of the cost, up to 1964/65, of providing the power requirements for the U.K. (Trafalgar Buildings, 1 Charing Cross, London, S.W.1.)

Solus-Schall describe methods of non-destructive testing in the December issue of their newsletter. (15 Clipstone St., Great Portland St., London, W.1.)

Lead News, a periodical published by the **Lead Development Association,** has an interesting article in the November issue on new lead materials for protection against radiation. (18 Adam St., London, W.C.2.)

Japan Atomic Industrial Forum has produced a directory of government agencies, associations and federations, industrial firms, universities and institutions in the nuclear energy field in Japan. (Tokyo, Japan.)

Fairey Review, the journal of the **Fairey Aviation Group** of companies, carries in its December issue illustrations of the products being made for the U.K.A.E.A. (24 Bruton St., London, W.1.)

National Research Corporation include all information on their high-purity tantalum in a four-page folder. (70 Memorial Drive, Cambridge 42, Mass., U.S.A.)

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Power Reactor Simulator

As we briefly reported in December, an Elliott nuclear reactor power plant simulator has been ordered by the Central Electricity Generating Board for delivery in July, 1959. To be installed initially at Berkeley nuclear power station, the unit is designed to assist in the training of reactor operators for current and future series of nuclear power stations. The Elliott No. 481 reproduces on suitable instruments the responses of an actual nuclear power plant to the operation of appropriate controls. The present model is arranged to simulate a power plant having a graphite-moderated, gas-cooled natural uranium fuelled reactor with multiple heat exchangers and using a dual pressure steam cycle.

Output signals corresponding to plant variables are produced by an electronic analogue computer, which is of unit construction and is so arranged that if required it may be adapted to simulate other types of reactor. Alternatively, additional computing units, indicators, etc., may be connected to the computer to enable the study of nuclear power plant control problems. A control desk is provided for the operator, and this with two separate boiler panels carries all the instruments and controls required for the operation of the plant.

(Elliott Bros. (London), Ltd., Century Works, Lewisham, London, S.E.13.)

1171

G.E.C. Buy Computers

To meet the growing demand of research and design, G.E.C.'s atomic energy division has ordered two additional computers, at a total cost of more than £140,000. These two machines, one an analogue and the other a digital computer, will be installed at Erith, Kent, Apart from expanding the available computing capacity, they will be particularly valuable in carrying out the extremely detailed and accurate calculations necessary in the G.E.C.'s extensive programme for the development of advanced types of nuclear power station.

The analogue machine is a general-purpose, type 231R "Pace" computer manufactured by Electronic Associates. It incorporates high-accuracy linear and non-linear computing components and a central patch panel, and has built-in checking facilities which will be of great value in programming. It can be coupled to the division's existing Elliott analogue computer, thereby considerably extending the potential range of calculations. The new analogue machine is due for delivery at the end of February.

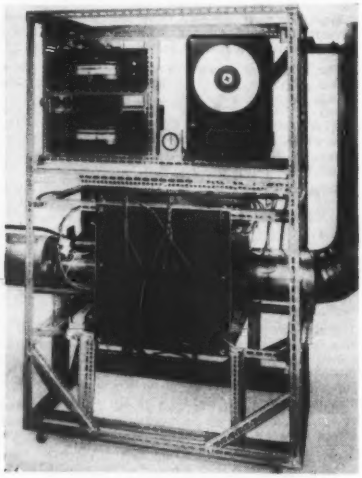
The second machine on order is a Mercury high-speed electronic digital computer, manufactured by Ferranti, and will be delivered towards the end of 1959. Pending its installation, Ferranti's computer services are being extensively employed. Meanwhile, tape-editing equipment has already been installed at Erith for programme preparation, so that the new digital machine can be put to full use as quickly as possible.

(Atomic Energy Division, The General Electric Co., Ltd., Erith, Kent.)

(Electronic Associates, Inc., New Jersey, U.S.A.)

(Ferranti, Ltd., Hollinwood, Lancs.)

1172



Test rig incorporating reactor grade graphite blocks (Foster Instrument).

Graphite Test Rig

A test rig incorporating reactor-grade graphite blocks was recently completed by Foster Instrument for the AEA. The extensive research tests carried out by the company's experimental department have included the measurement of temperature gradients in all planes through varying thicknesses of graphite, surface temperatures in the fuel element and isotope channels and time constants of various types of thermocouples.

These tests were carried out under both static and dynamic conditions. Under the latter air-flow rates of 37,000 to 87,000 cu. ft. per hour were required necessitating the development of special types of contact thermocouples. The heat was created by electrical blanket heaters on all sides of the block assembly and special cartridge and vee-formed heater elements mounted on dummy fuel cans. By controlling air-flow rates and temperature, operational conditions representative of any section throughout the entire depth of the reactor were simulated.

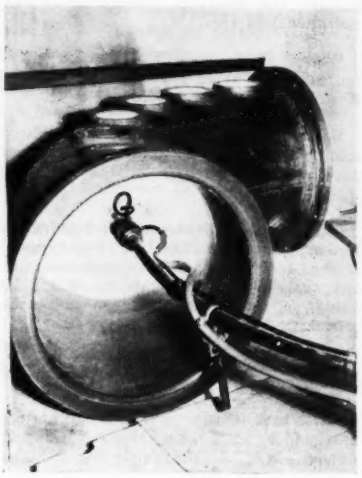
(Foster Instrument Co., Ltd., Letchworth, Herts.)

1173

Enamelling the ZETA Torus

Experimental work in connection with the development of ZETA has been carried out by Ferro-Enamels of Wombourne, Wolverhampton, under a running contract from A.E.R.E., Harwell. The tests have involved the vitreous enamelling of the interior surface of segments of the torus to give electrical insulation against a current in the region of 200,000 amp.

Although the company has a great deal of experience of enamelling aluminium, a number of difficulties were encountered in getting a good coverage of enamel. There were further complications in that a far higher standard of finish was required than that which would be commercially acceptable.



Enamelling a ZETA torus segment. The rotating head of an automatic spraying unit is retracted at a continuous rate of travel.

In order to obtain a finish free from microscopic pin-holes caused by dust in the atmosphere, Ferro-Enamels found it necessary to pressurize their development laboratory and to filter the air drawn into it. Experimental segments were subsequently tested for porosity with an arcing probe. At the present stage the company is confident that segments can be enamelled with only one pin-hole per 200 sq in. in area. Work is now in progress to obtain an even better finish.

(Ferro-Enamels, Ltd., Wombourne, Wolverhampton.)

1174

Three Digit Voltmeter

A digital voltmeter has just been put into quantity production by Ferranti. The voltmeter is the three digit model D101 which covers the range of 0.01 V to 999 V d.c. with automatic ranging, polarity and decimal placement and with an accuracy of 0.1% on any of the three ranges which are 0.01 to 9.99, 10.0 to 99.9, and 100.0 to 999.0 volts d.c. The average reading time is 0.7 seconds.

In operation, the input voltage is compared to the voltage from a Kelvin-Varley potentiometer. Any difference actuates stepping switches until a balance is achieved, enabling the measured voltage to be presented digitally in the form of ¾-in. high illuminated numerals in a 1¼ by 5¼ in. display area. The reference voltage is from a bank of mercury cells. Stability is achieved by the use of a transistorized amplifier and high-grade choppers. Printed circuitry has been extensively used to ensure reliability.

The instrument has been adapted so that a printing device can be coupled to it, and a

printer is at present under development. It is also possible to have a remote read-out so that the indicator unit can be located in any suitable position, if necessary at a distance from the voltmeter or other digital instrument.

(Ferranti, Ltd., Hollinwood, Lancs.)

1175

Ferranti three-digit voltmeter.

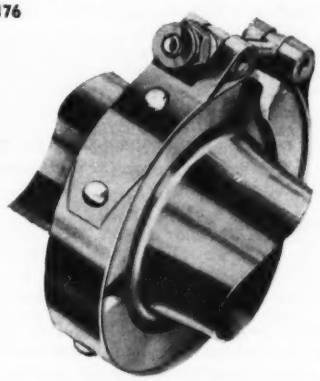
High Temperature Coupling

A new type of coupling for use at elevated pressures and temperatures has been developed by King Aircraft Corporation. Termed Conoseal, the unit is based on the vee-band clamp principle. It consists of a male and female flange and all-metallic gasket. The flanges are suitable for either lap or butt welding to the pipe line or duct. The standard range offered covers pipe bores from $\frac{3}{4}$ in. to 10 in. diameter, and can be supplied in aluminium alloy, mild steel, stainless steel or Inconel materials, dependent on the temperature and fluid characteristics involved. Non-standard couplings have been manufactured up to 36 in. diameter. The operating temperature ranges from $-184°C$ to $+980°C$. The coupling has been tested at pressures of up to 6,000 p.s.i.

The vee-clamp coupling offers great advantage where rapid connection and disconnection is required. Low weight and small envelope characteristics are considerable when compared with bolted flange joints.

(King Aircraft Corporation, Hillington, Glasgow, S.W.2.)

1176



Vee-clamp coupling for elevated temperatures and pressures. (King Aircraft Corp.)

This heat exchanger tube plate forging is one of four recently supplied for the 134 MW Yankee Atomic power plant at Rowe, Massachusetts. Each forging was produced in a 10,000 ton open die press from one 77 in. dia, 105 ton ingot of open-hearth steel. Forged dimensions were 89 in. dia by 33½ in. high. The forgings were rough machined on this 100-in. vertical boring mill with a carbide tipped tool to 85 in. dia by 26$\frac{15}{16}$ in. thick through the flange. (United States Steel, 525 William Penn Place, Pittsburgh 30, Pa., U.S.A.)

1177

Field Monitoring System

The new Elliott beta-gamma field monitoring system consists of weatherproof detector units feeding into a central multipoint recorder. Each field unit may be located up to 2,000 metres from the central station, and provides signals of the local beta and gamma activity. The detector unit comprises an aluminium casting which forms a protective cowl for a geiger tube and is so shaped that a known ground area is monitored. The casting houses also, the transistorized amplifier, local ratemeter and a 2½-in. moving coil instrument giving visible indication of local count rate.

The detecting element is either an all-metal gamma counter or a thin-walled beta/gamma counter. The pulses from the counter are amplified by transistor circuits and transmitted by coaxial cable to the central recording station. Power supply to each field station is 12 V d.c. at 200 mW and is carried by the common signal cable. E.H.T. supply for each counter is generated in the individual heads so that failure of one supply does not render all monitors inoperative.

The multipoint recorder is of the Bristols Dynamaster type and a record of up to 12 field stations is displayed in multicolour dot form on an 11-in. strip chart. Each remote detector is scanned in turn by the switch mechanism at an interval of 30 or 60 sec per unit. The recorder has its own transistorized ratemeter which is connected to the balancing amplifier and, in turn, to each signal input. Alarm contacts may be provided to give warning of high- or low-level signals and the settings are adjustable over 100% of the recorder range.

(Elliott Bros. (London), Ltd., Century Works, Lewisham, London, S.E.13.)

1178

Measuring Neutron Flux

The type 1285A logarithmic pulse counting equipment manufactured by Clifford and Snell is for measuring neutron flux in connection with nuclear reactor instrumentation, where as an alternative or complement to log d.c. equipment, a much lower neutron level can be detected and counted, particularly under conditions of high gamma radiation background. One of three forms of counter may be used: (a) boron-trifluoride (BF_3) proportional counter; (b) fission chamber: and (c) scintillation counter.

At present the BF_3 counter is most generally used. This (as does the scintillation counter) requires a positive polarizing voltage of the order of 1,500 volts, supplied from an electrically stabilized power supply. A fission chamber requires a lower voltage of the order of 300, which can conveniently be supplied from batteries. An H.T. supply unit (normally used for supplying the ionization chambers in d.c. counting equipment) is suitable.

The output pulses from (a) or (b) above are of a milli-volt order, and as they constitute amounts of charge, the actual voltage amplitude is dependent on the amount of any associated capacity due to feeder cable, or connectors. Where such counters are mounted remotely from the main equipment, a head amplifier is required near the counter in order to keep the feed cable to a minimum. The scintillation counter produces a pulse amplitude of an order nearer a volt: it has, however, a high internal impedance and, in consequence, a cathode-follower-type head is generally employed.

The system employs a discriminator so that only those pulses due to neutrons are counted, whilst unwanted responses due to gamma-radiation, or noise, are ignored. The discriminator requires an input of an order of 5-50 volts for reliable operation; hence a pulse-counting channel must include a main pulse amplifier to bring the counter pulses to this level. Suitable units are types 1049B or C (now 1518) and 1366A, with their associated heads. They are required to handle pulses of the order of 1 μsec for counter type (a) and 0.1-0.2 μsec order for (b) and (c). The corresponding rise time of the pulses is of the order of $\frac{1}{3}$th of the duration.

The counting equipment proper consists of two units: (a) fast discriminator and scaler type 1366A (now 1516A); (b) logarithmic ratemeter type 1285A. The discriminator unit also embodies a fast scale of 10 circuits. By this means the ratemeter can be made to register the maximum count rate possible from counters type (b) and (c), which is of the order 10^4 counts/sec. (The maximum count rate with BF_3 counter is of the order 10^5 counts/sec.) A separate output direct from the discriminator circuit (i.e., unscaled) is also fed to the log-ratemeter in order to produce a smooth indicator response at low counting rates.

(Clifford and Snell, Ltd., Carshalton Road, Sutton, Surrey.)

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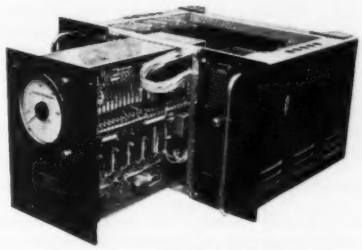

Logarithmic ratemeter, type 1285B, by Clifford and Snell.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 796,989. Neutronic reactor fuels. General Electric Co. (U.S.A.).

Fuel elements constructed from alloys of uranium-235 and a metal, such as aluminium or zirconium, containing a fine, even dispersion of boron-10. As these fuel elements are consumed, the boron-10 particles which have a very high neutron capture cross section are gradually transmuted to lithium which has a much lower neutron capture cross section. The alloying metal acts as a relatively inert diluent for the uranium and also reduces the rate of corrosion of the uranium at elevated temperatures. With such fuel elements the amount of external control to regulate the rate of reaction is reduced as the ratio of the number of neutrons produced to the original number of neutrons initiating the fissions remains virtually constant over a long period.

B.P. 796,991. Nuclear reactors. J. Diamond, J. Smith. To: U.K. Atomic Energy Authority.

Certain advantages of natural water moderated reactors are counteracted by the disadvantages of low critical temperature coupled with high critical pressure, which have also to be considered when using heavy water or liquid hydrocarbons as moderators. Such disadvantages can be overcome by heat insulation between channels carrying the reactor coolant and the moderator, by a gas space, with or without a solid insulator. The arrangement is particularly useful in sodium cooled water moderated reactors. An insulating space also acts as a barrier and, in case of leaks, an inert scavenging gas circulated through the insulating channels can be used to detect such leakage.

B.P. 796,992. Nuclear reactors. J. Diamond, S. G. Bauer. To: U.K. Atomic Energy Authority.

One of the serious difficulties of reactor design is the provision of service facilities for the radioactive circuit including pipes, pumps, heat exchanger, etc. By making the reactor of a number of removable self-contained units each with a reactive section, heat exchanger, primary coolant circuit, heat exchanger, circulator and shielding, servicing can be limited to a single unit. The reactor can be shut down, and after allowing time for activity decay, the secondary coolant connection can be uncoupled and the unit removed and replaced by a similar unit.

B.P. 797,485. Low temperature nuclear reactors. To: Allmanna Svenska Elektriska AB. (Sweden).

In reactors adapted for heating purposes the desired temperature of the cooling medium leaving the reactor is about 130°C. at which a pressure of 7 atm. is sufficient to prevent boiling. Instead of having the cooling system only under pressure, a common moderator and cooling system is provided under the same pressure, the heavy water first flowing through the moderator vessel and then serving as cooling medium flowing through tubes around the fuel rods. The pressure vessel surrounding the reactor vessel is filled with neutron reflecting material (graphite). The cover for the reactor vessel is built as a collecting vessel into which run the tubes containing the fuel rods. The reactor vessel then may be made thin to reduce neutron absorption.

B.P. 797,692. Shields for nuclear reactors. I. J. Lockyer. To: Morgan Crucible Co., Ltd.

Blocks of graphite in which a boron compound is dispersed preferably resolidified from the molten state *in situ* in the pores of the graphite material.

B.P. 797,725. Power plant including a nuclear reactor. W. Eccles. To: Metropolitan-Vickers Electrical Co., Ltd.

For maximum power production from a given rate of flow of heat from the reactor, the heat carrier must be returned at as high a temperature as possible, and since the maximum temperature at which the heat carrier leaves the reactor is limited it must be circulated as rapidly as possible. Thus operation at a steady heat output is desirable and great difficulties arise when varying loads are to be supplied. To overcome these difficulties, a cascaded arrangement of reactor heated boilers is proposed operating at different pressures together with a furnace heated boiler supplying additional motive fluid which is used when the load requirements exceed the reactor output. Means are further provided for controlling the return temperature of the heat carrier.

B.P. 797,872. Apparatus for generating electricity by thermionic emission. H. Hurst.

A thermionic cell with two or more electrodes in a heat-resisting envelope which may be evacuated or contain gas or vapour, is heated externally to cause a flow of electrons from an emissive electrode to a collector electrode such that, when these electrodes are connected through an external load circuit, a net current flows through the system. Pellets of radioactive material may be embedded in the emissive material or external irradiation may be carried out by exposure to a radiation source and may be made selective by shielding. Cells may be connected to systems either in series or parallel to increase voltage or current.

B.P. 797,882. Manipulating devices. J. Britt. To: Rolls-Royce Ltd.

The device is intended for handling articles by remote control, e.g., in a space containing liquid sodium at high temperature from which the mechanism must be protected, and which itself must not be contaminated by any lubricant or coolant. A rigid tubular casing with straight portions connected by a curved portion is provided with internal guide faces for a girder structure of a pair of flexible strips and interconnecting links. The strips are in sliding contact with the guide faces and by interlocking of the links and strips in one straight portion, a rigid structure is formed capable of supporting bending loads in the centre-plane of the curved section of the casing. The interlocking and unlocking is effected by projecting the girder member more or less from the end of one straight portion. Suitable gripping means is carried at the operative end of the girder. The casing is made rotatable about an axis through one of its straight parts so as to be movable over a large area.

B.P. 798,029. Process for the preparation of carbonaceous material suitable for use in a nuclear reactor either as moderating material or in the construction of a reflector. To: N.V. De Bataafsche Petroleum Maatschappij (Netherlands).

Deuterated heavy aromatic hydrocarbon material is submitted to carbonization. The term "heavy aromatic hydrocarbon material" means material consisting wholly or mainly of one or more polycyclic compounds. The moderating effect of the material obtained by this process is considerably higher than that of graphite, for example.

B.P. 798,282. Fuel elements for nuclear reactors. G. D. Bell. To: Atomic Energy Authority.

The element consists of a hollow uranium cylinder with an inner zirconium sheath pressurized tight onto the uranium, and an outer zirconium sheath spaced from the uranium cylinder by a uniform 0.1 inch gap so as to have poor heat transfer. The outer sheath is contacted by inflowing coolant, the inner sheath by outflowing coolant. The outer sheath serves for carrying the fuel element in a zirconium lined channel of a graphite moderator structure and sustains all the stresses due to the weight of the fuel element while the inner sheath remains relatively unstressed.

B.P. 798,434. Fuel elements for nuclear reactors. A. Blainey, H. Lloyd. To: U.K. Atomic Energy Authority.

A tubular fuel element (enriched uranium) is provided with a sheath of a protective substance (beryllium) by compacting layers of the substance over and around the fuel tube. A removable core of lead, tin, bismuth or other low melting point metal to deform under compaction and transmit isotropic pressure is used to define the interior diameter of the element during compacting and subsequent sintering of the powdered sheath in a demountable die of "Nimonic" nickel-chromium alloy, or nickel titanium carbide.

B.P. 798,441. Heat transfer systems. J. B. Morris. To: U.K. Atomic Energy Authority.

Into a bed of heat-generating particulate material is injected a liquid which, at a given bed temperature, flash-evaporates. The bed may be constituted by a powder of fissile and moderating material (i.e. a nuclear reactor core) into which water is injected and from which the flash is fed directly to a steam turbine system.

B.P. 798,466. Nuclear reactors. W. Macrae, A. L. Howie. To: C. A. Parsons and Co., Ltd.

Refers to a control rod in articulated or link form. The links may have varying degrees of neutron-absorbing capacity and may be made of tubes filled with material producing fissile material under irradiation (e.g. thorium). The uppermost link rests with radial arms on the reactor core.